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Discover the wonders of the universe

I had a brief conversation with someone recently who had no association with NASA or any formal qualifications in the sciences. They were commenting, apparently with near certainty, on how they thought the mystery jelly-doughnut rock – discovered in the Gale Crater early this year by the Curiosity rover – could be of extraterrestrial origin. I paid about as much mind to that as any other spurious internet theory, but their rather fantastic leap of logic was partly attributed to the fact that NASA hadn't immediately flagged the anomalous-looking Martian mineral up and offered an explanation, or apparently made any investigation into it.

That got my attention and made me think of a more-recent announcement that hit the headlines – the confirmation of the Big Bang/cosmic inflation theory. When a group of scientists in the South Pole found an anomalous signal in their telescope data that suggested a monumental discovery, they didn't tell the national papers. Instead they quelled their excitement and spent a year trying to prove the signal was nothing more than a ripple in space, a passing comet or a spot on the lens.

It brings to mind two quotes, Arthur Conan Doyle's famous: "When you have eliminated the impossible…" and Asimov's equally pertinent: "The most exciting phrase to hear in science…" It's infinitely more difficult to come to far-flung conclusions when you're an expert but if, after numerous attempts to shoot your own findings down, it's the only conclusion left, that epiphany must feel like a fairy-tale ending.

Ben Biggs
Editor

Crew roster

Jonathan O'Callaghan

- This is Jonny's last issue. After two years of service, he's decided to join Mars One… Good luck!

Gemma Lavender

- Gemma was furious after missing a second Mars opposition in a row

Shanna Freeman

- Shanna takes us on a journey to an exoplanet star system: Kepler-64

Laura Mears

- Why should we return to the Moon? Laura explains all in our cover feature

© Steffen Richter, Harvard University

> "We kept seeing this extra signal and actually we were pretty frustrated that we couldn't get rid of it!"
> **Professor Jamie Bock, BICEP project co-leader**

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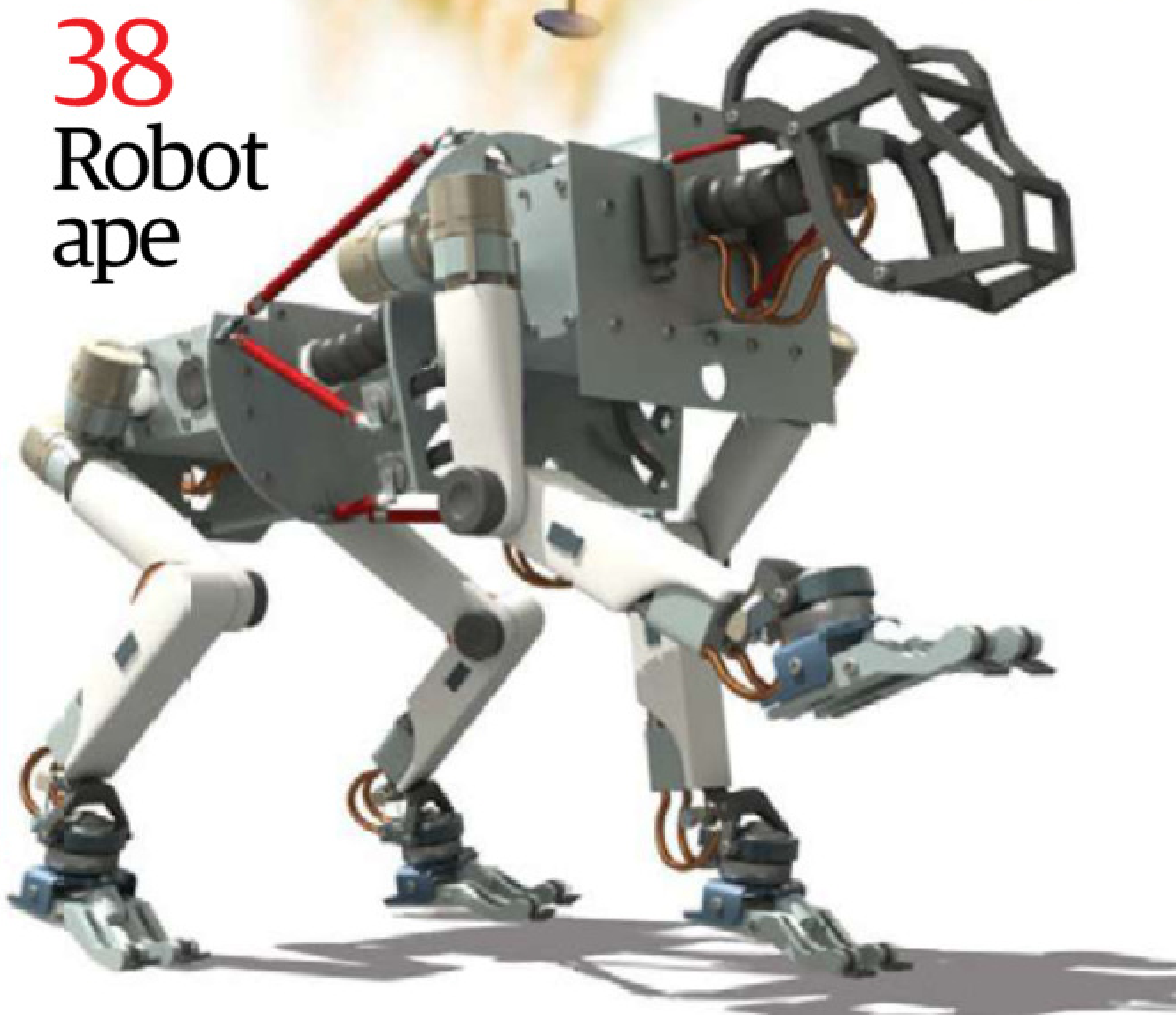

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“Suddenly, for me it was this watershed moment and I thought, ‘It's real!’”

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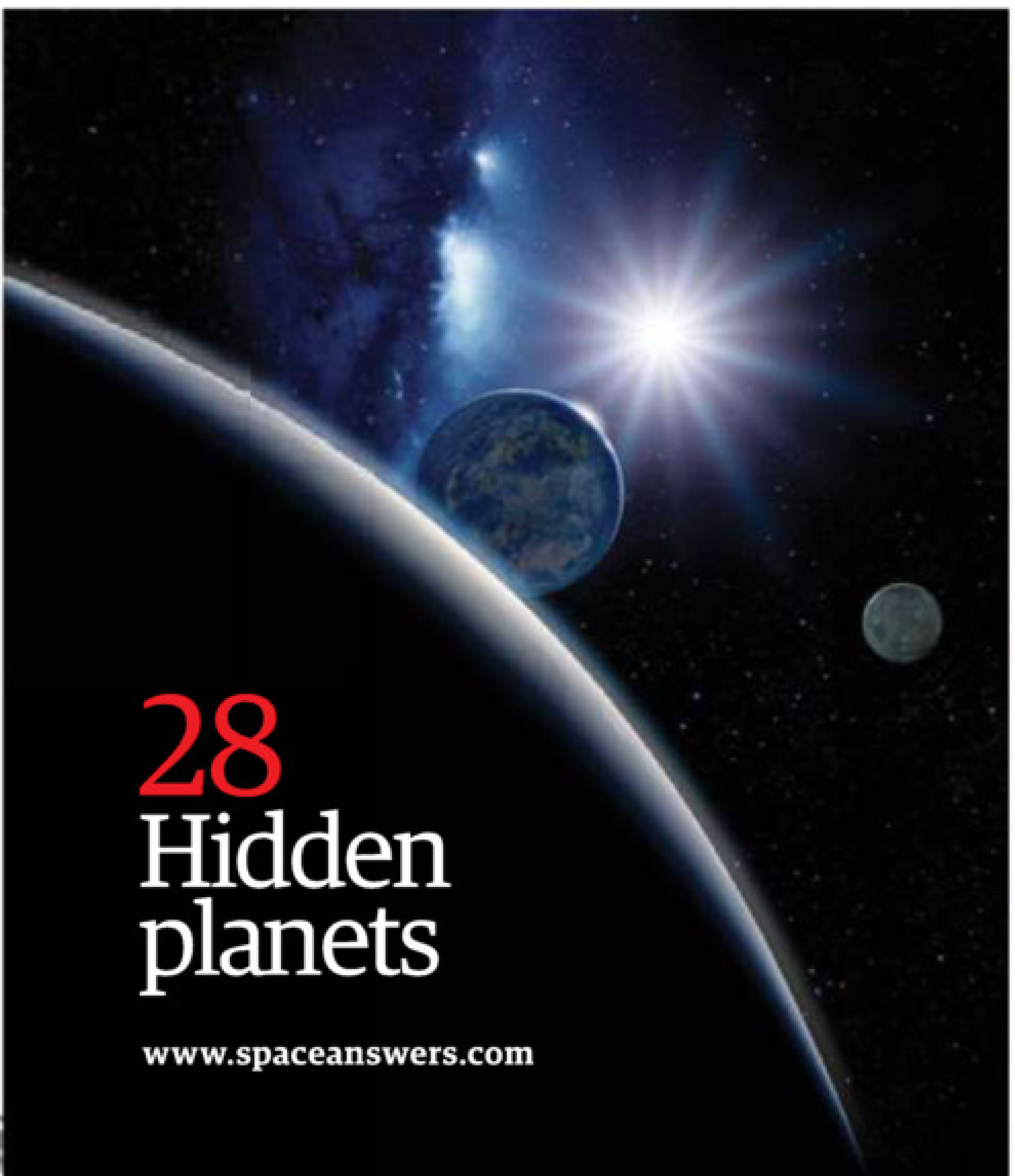

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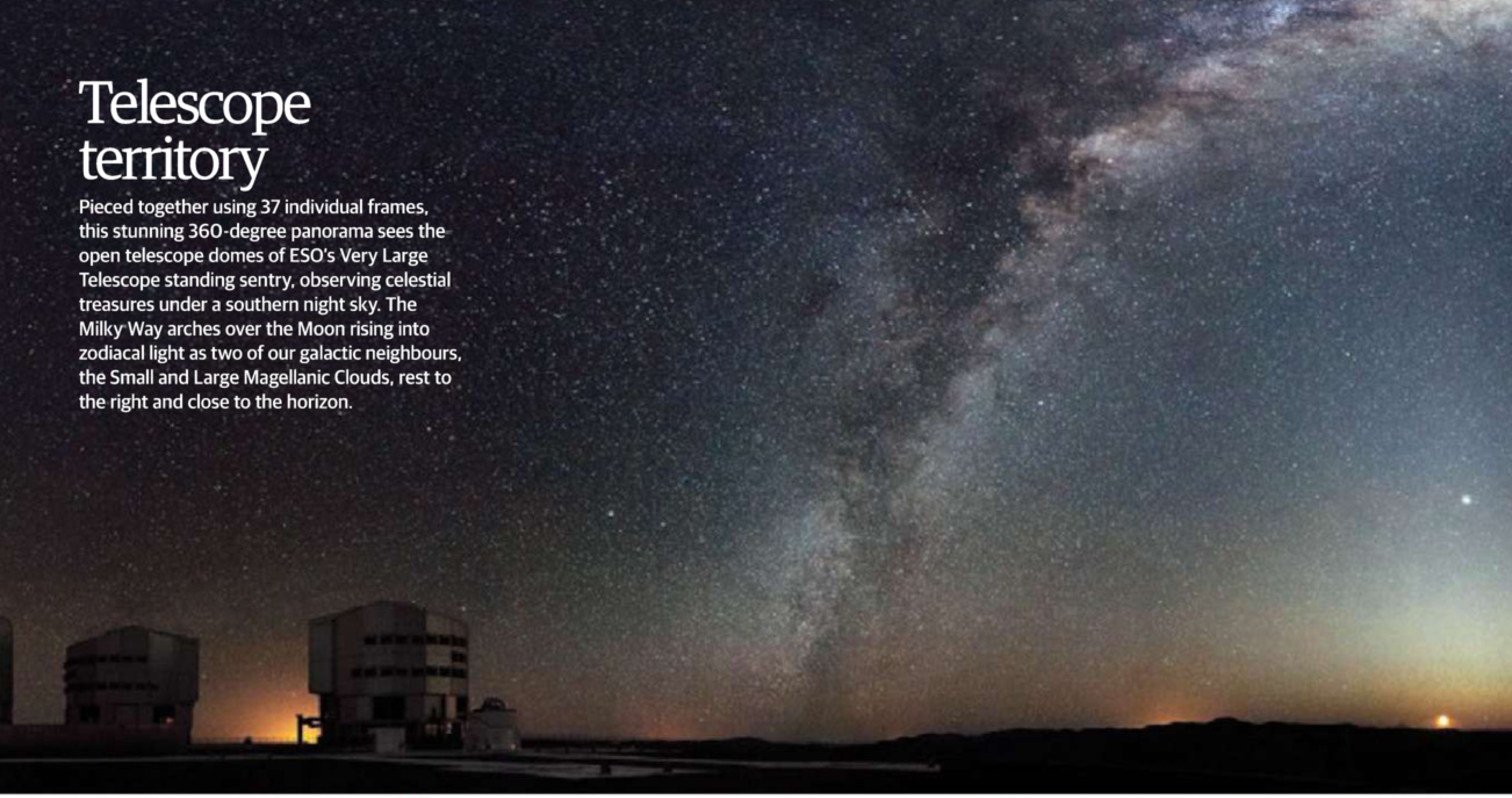
On the Hubble diet

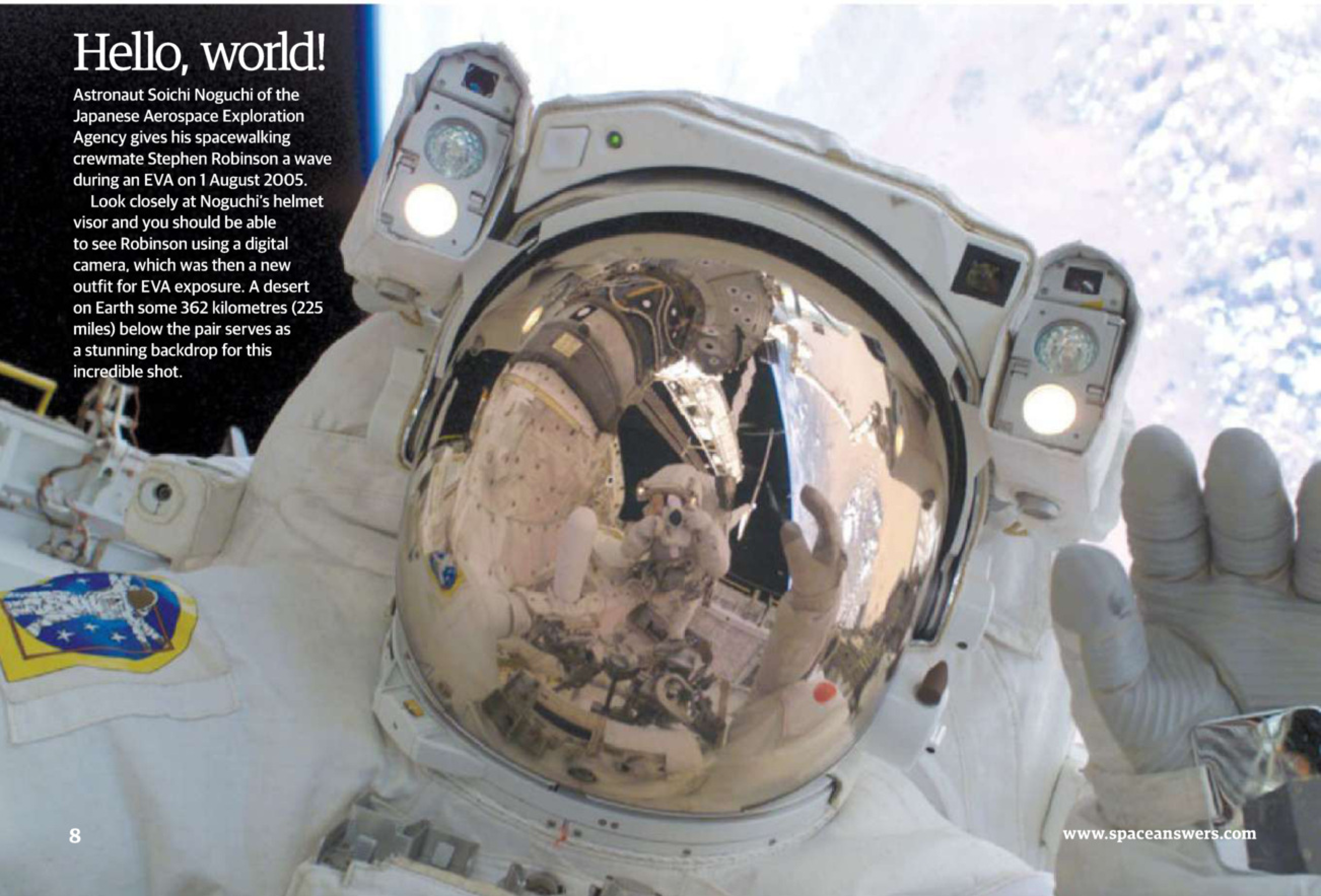
Roughly 8,000 light years away and nestled in the small open star cluster Pismis 24, young bright star Pismis 24-1 was one of the top candidates for the title 'Heavyweight Champion of the Milky Way'. That is until Hubble turned its telescopic eyes to the star, resolving it into two stellar companions. This shrunk its original 200 solar mass bulk, halving it to around 100 solar masses.

The large emission nebula NGC 6357 can also be seen, peeking like a warm-hued temple on the right of this image. This region of thick, freezing-cold chunks of gas and dust is blasted by the intense ultraviolet radiation of its young stars.



Telescope territory

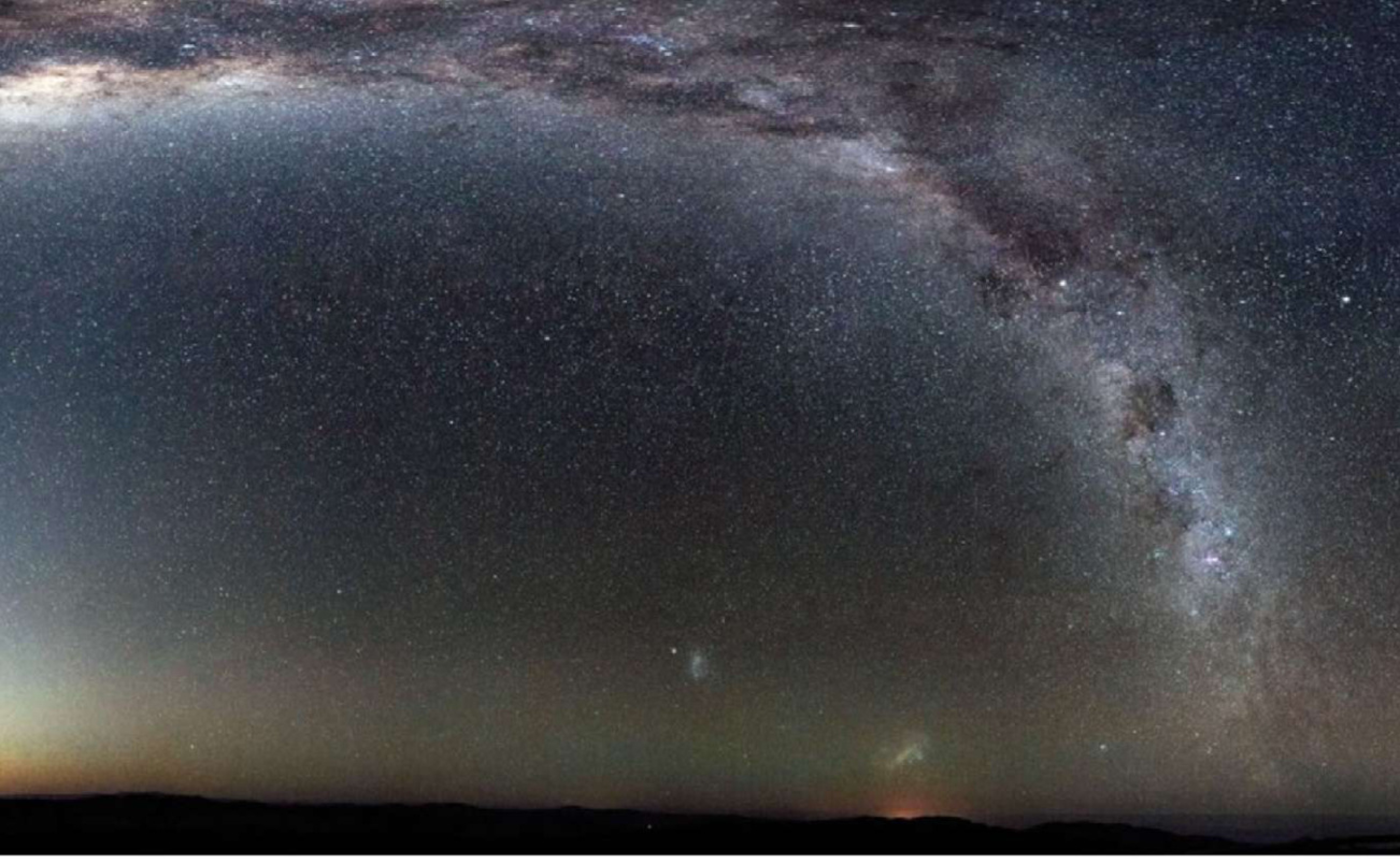
Pieced together using 37 individual frames, this stunning 360-degree panorama sees the open telescope domes of ESO's Very Large Telescope standing sentry, observing celestial treasures under a southern night sky. The Milky Way arches over the Moon rising into zodiacal light as two of our galactic neighbours, the Small and Large Magellanic Clouds, rest to the right and close to the horizon.

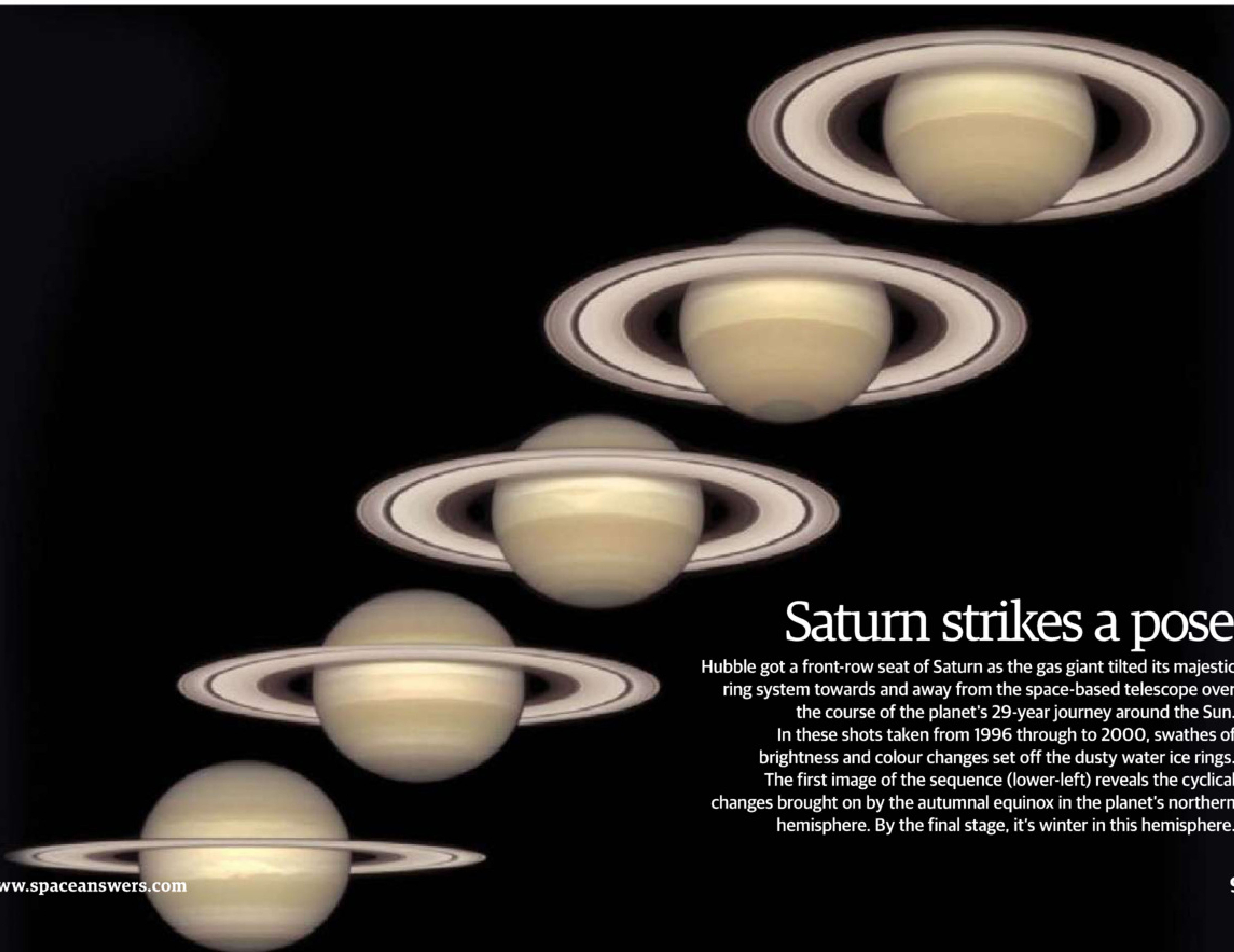


Hello, world!

Astronaut Soichi Noguchi of the Japanese Aerospace Exploration Agency gives his spacewalking crewmate Stephen Robinson a wave during an EVA on 1 August 2005.

Look closely at Noguchi's helmet visor and you should be able to see Robinson using a digital camera, which was then a new outfit for EVA exposure. A desert on Earth some 362 kilometres (225 miles) below the pair serves as a stunning backdrop for this incredible shot.





Saturn strikes a pose

Hubble got a front-row seat of Saturn as the gas giant tilted its majestic ring system towards and away from the space-based telescope over the course of the planet's 29-year journey around the Sun. In these shots taken from 1996 through to 2000, swathes of brightness and colour changes set off the dusty water ice rings. The first image of the sequence (lower-left) reveals the cyclical changes brought on by the autumnal equinox in the planet's northern hemisphere. By the final stage, it's winter in this hemisphere.

Homeward-bound

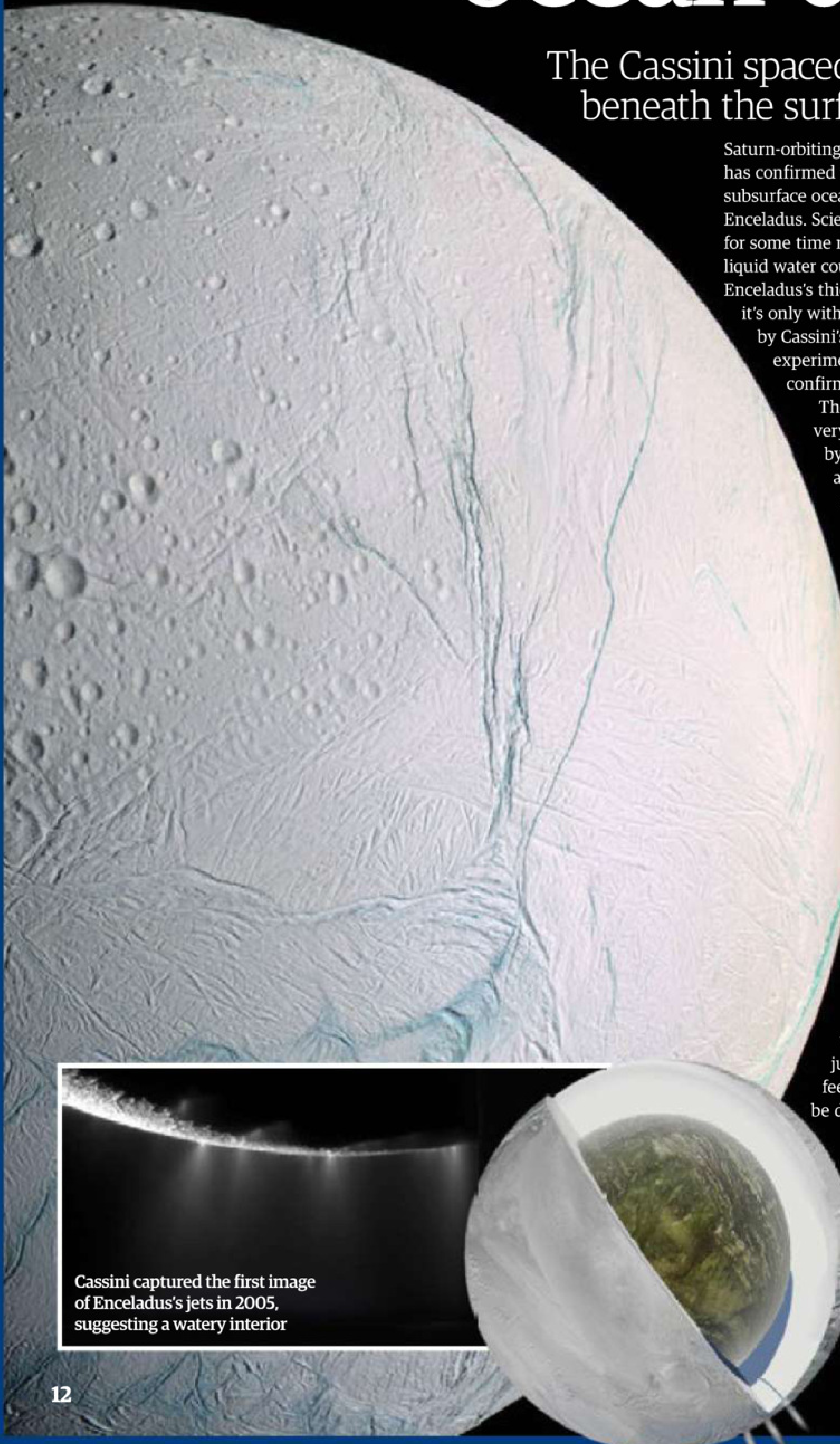
Photographed by the STS-125 crew on flight day ten, the view of the journey home for Space Shuttle Atlantis is paved by the darkness of space. Earth teases us, revealing itself only as a thin line of its atmosphere that's marked by the brilliance of the Sun.

The shuttle's payload bay, remote manipulator system robotic arm, orbital manoeuvring system pods and a vertical stabiliser, are all featured in this stunning image, which paints a picture of the breathtaking feat of space exploration.

© NASA; ESO

Icy moon's subsurface ocean discovered

The Cassini spacecraft has spotted a liquid interior beneath the surface of Saturn's moon Enceladus



Cassini captured the first image of Enceladus's jets in 2005, suggesting a watery interior

Saturn-orbiting space probe Cassini has confirmed the existence of a subsurface ocean on the icy moon Enceladus. Scientists have suspected for some time now that a body of liquid water could exist beneath Enceladus's thick ice crust, but it's only with the data provided by Cassini's radio science experiment that they can now confirm this.

The craft was pulled very slightly off course by the moon's gravity, affecting a change in its velocity of between 0.2 to 0.3 millimetres per second. "By analysing the spacecraft's motion in this way, and taking into account the topography of the moon we see with Cassini's cameras, we are given a window into the internal structure of Enceladus," said planetary scientist and member of the Cassini radio science team, Luciano Iess. Though the difference in velocity was tiny, just over a metre (3.28 feet) per hour, it could be detected in the signal transmitted back to Earth. From this, variance in the affect of Enceladus's gravity could be measured and ultimately the difference in the distribution of the moon's interior mass was confirmed.

"The perturbations in the spacecraft's motion can be most simply explained by the moon having an asymmetric internal structure, such that an ice shell overlies liquid water at a depth of around 30 to 40 kilometres (18 to 25 miles) in the moon's southern hemisphere."

Scientists think that the sea most likely stretches from the south pole of the moon, up to about 50 degrees in the southern latitude, based on Enceladus's topography and regional temperatures observed at its surface. However, a global ocean cannot be ruled out just yet.

The sixth-largest moon of Saturn has been known to contain some liquid water and a suspected subsurface reservoir ever since 2005. That year the Cassini spacecraft began its round of close flybys of Enceladus, which enabled it to pick the detail of the moon's surface features out – including jets of water spouting from near its south pole. Cryovolcanos were observed jetting plumes of water vapour and volatiles, at the rate of 200 kilograms (440 pounds) per second, into the atmosphere and falling back down as a kind of snow.

The way the jets reacted to the changes in the gravitational stress on Enceladus from its giant parent Saturn suggested a large body of water beneath its crust. ■

> "An ice shell overlies liquid water at a depth of around 30 to 40km in the moon's southern hemisphere"

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Sentinel 1A, the first satellite dedicated to the EU's Earth-observation programme Copernicus, was successful launched from Kourou, French Guiana

Liftoff! Europe's first Earth-observation satellite successfully launched

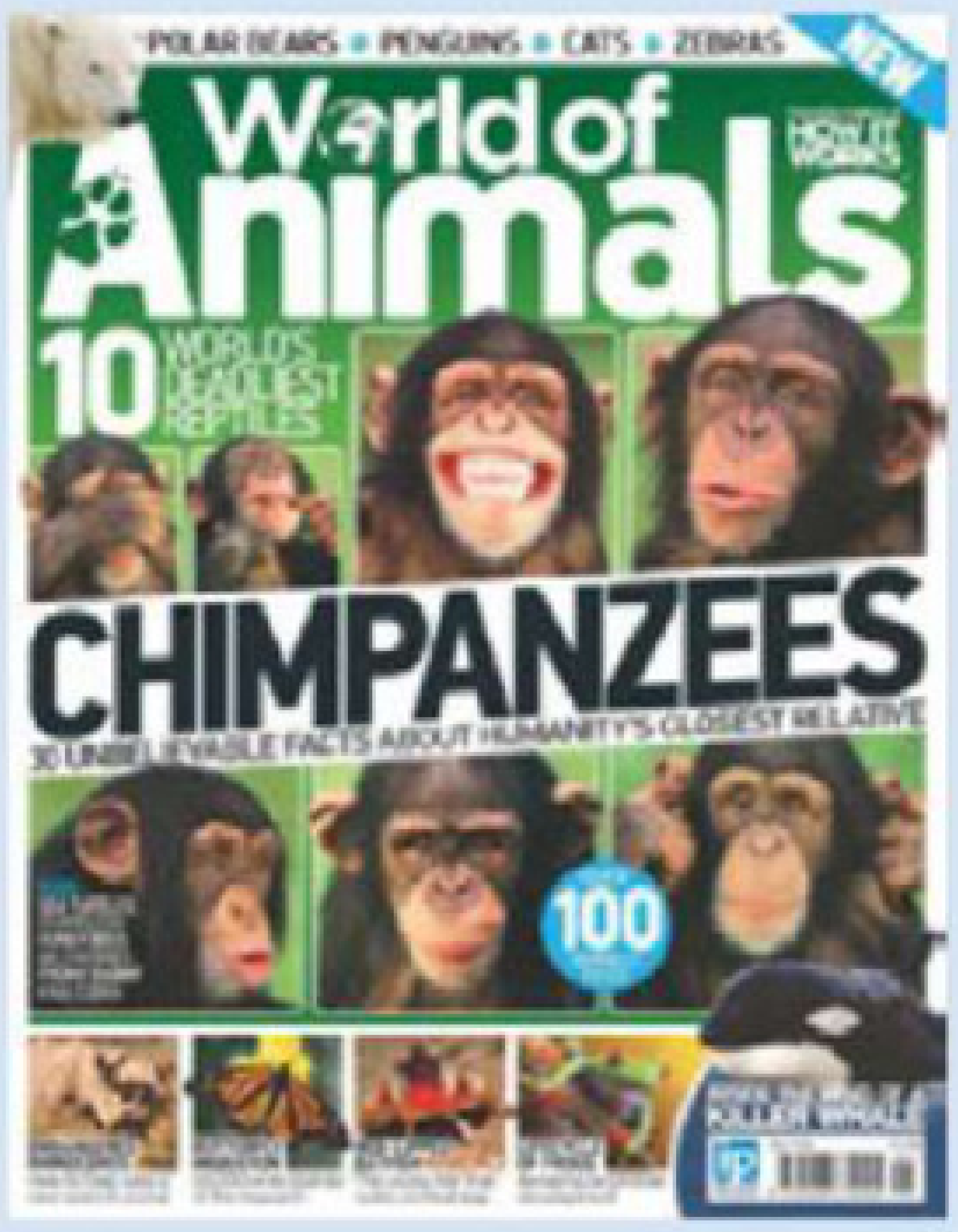
The first satellite dedicated to the EU's Earth-observation programme was successfully launched from Europe's spaceport at Kourou, French Guiana

Early April saw a major milestone being reached as Sentinel 1A, the first satellite dedicated to the European Union's Earth-observation programme Copernicus, successfully left Earth from French Guiana.

Copernicus, which marks the achievement of Europe's involvement in space activities, will ensure the regular monitoring and observation of our planet's surface, scanning its atmosphere, oceans and continental surfaces to provide reliable information to support a wide range of environmental and security applications and decisions.

"Thanks to Sentinel 1A, which is the first of a constellation of satellites dedicated to the Copernicus programme, new eyes will observe our living Earth as never before and these eyes will be European," explained Antonio Tajani, the European commission vice president.

"The data provided... will enable considerable progress in improving maritime security, climate change monitoring, as well as providing support in emergency and crisis situations..." Tajani concluded. ■



World of Animals issue 6 on sale now!

From the slovenly sloths of the Amazon rainforest to the predatory polar bears of the Arctic Circle, **World of Animals** is a new monthly magazine from the makers of **How It Works** and **All About History** that takes a unique look at wonderful wildlife from all over the globe.

With breathtaking photography, captivating stories and stunning illustrations, each issue offers the safari of a lifetime that takes the reader on a fact-filled tour of the planet's favourite wildlife.

World of Animals can be found for iOS and Android, available from **www.greatdigitalmags.com** and is accompanied by a brand-new companion website: **www.animalanswers.co.uk**. You can connect with the team on Twitter @WorldAnimalsMag and Facebook at **www.facebook.com/worldofanimalsmag**. ■

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Martian crater held a lake

It appears that Mars' Gusev Crater did in fact hold water at some time in its history, as was thought.

A high rocky outcrop has shown evidence of hydrothermal activity, suggesting a rather high amount of magnesium-iron carbonate minerals.

Hubble measures ten-times further

Enlisting the help of Hubble, astronomers are now able to measure stars as far as 10,000 light years away - ten-times further than before - and more accurately than previous.

Astronomers find possible exomoon

A team of astronomers believe they could have spotted the first signs of a natural satellite that could be orbiting an exoplanet.

The find was made by watching a chance encounter of objects that can only be made once.

Work starts on OSIRIS-REx

The go-ahead to build OSIRIS-REx, a spacecraft set to visit near-Earth asteroid Bennu in 2018 to collect samples, has been given by NASA.

The mission aims to broaden our understanding of the early Solar System as well as the source of the organic materials and water that made life on Earth possible.

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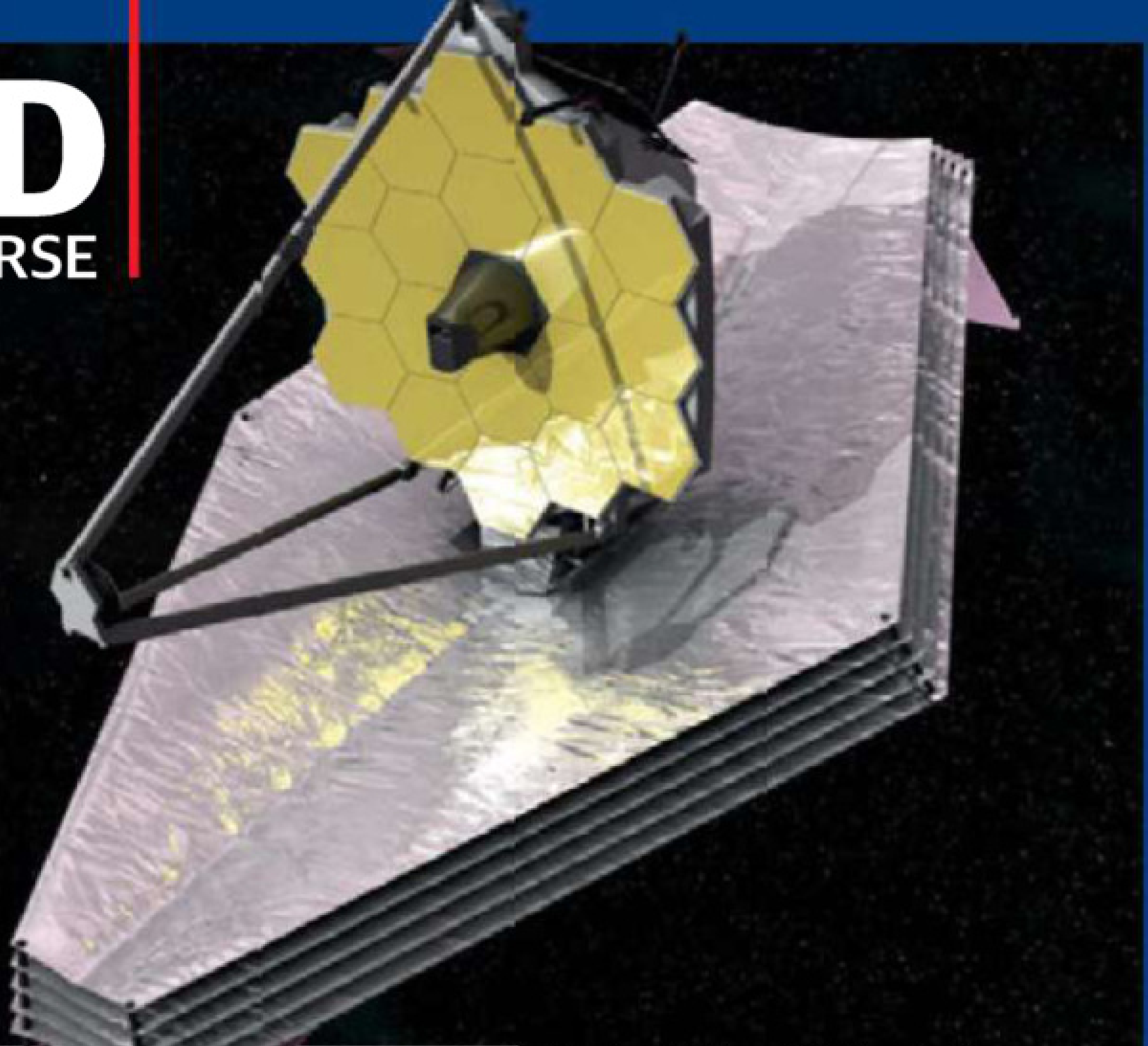
Final instrument installed on JWST

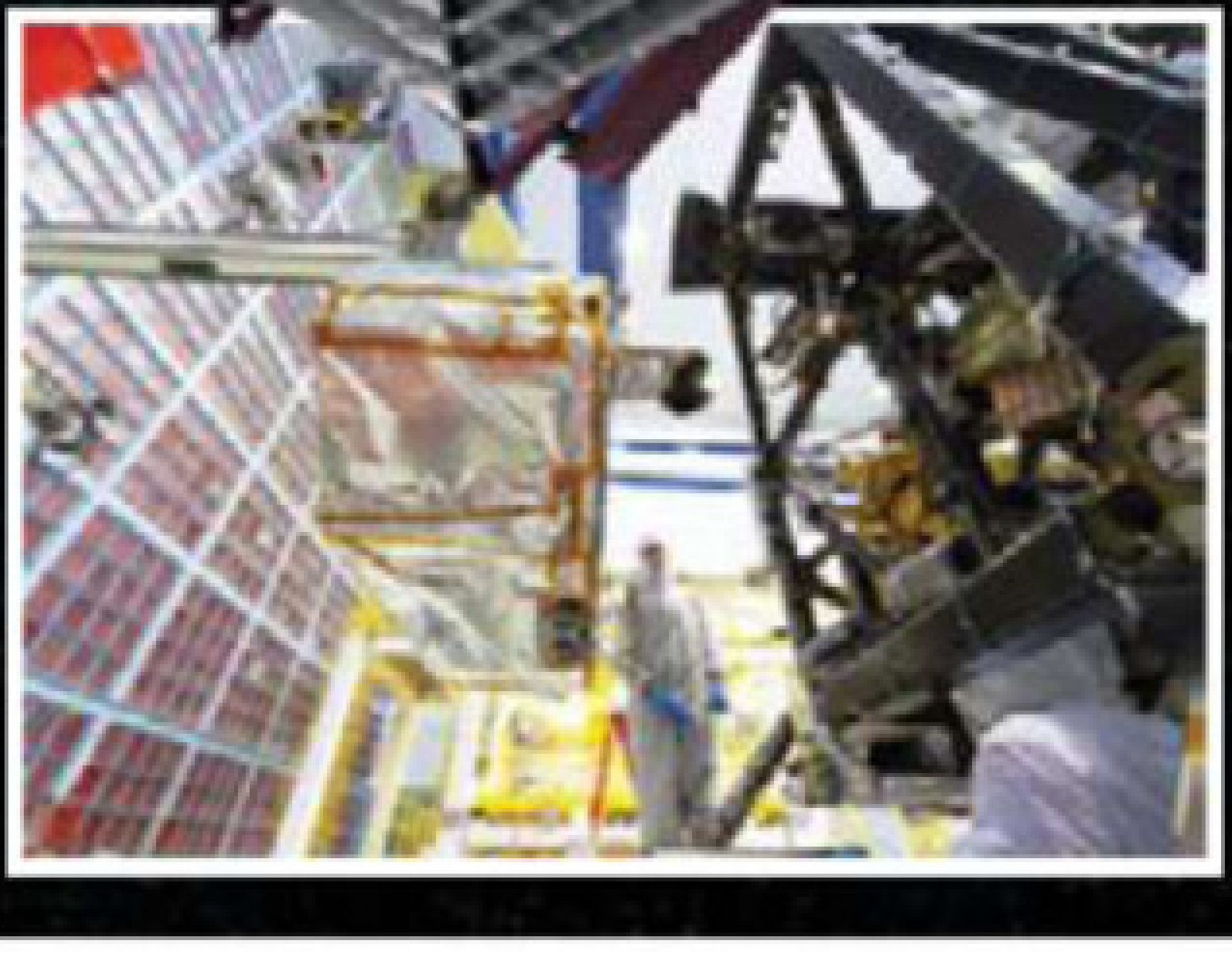
The JWST reaches a milestone as its central unit is completed, keeping it on track for a 2018 launch



The final of four instruments that completes the heart of the James Webb Space Telescope (JWST) has been installed inside the world's largest clean room at NASA's Goddard Space Flight Center.

The 6,500-kilogram (14,300-pound) successor to the long-serving Hubble Space Telescope, that's been slated for launch in 2018, will help us unlock the history of our universe. The new craft aims to search from the first glows after the Big Bang, through to the formation of star systems capable of supporting life and all the way down to the fine details that govern the evolution of our own Solar System. Adding the Near-infrared Spectrograph at its heart, scientifically known as the Integrated Science Instrument Module (ISIM), this is yet another a milestone that will enable the telescope to do just that.

"NIRSpec is a multi-object spectrograph, which means it will be capable of observing 100 objects in the cosmos simultaneously," says Maurice te Plate, both the JWST's system integration and test manager. "For each of these objects the captured light will gradually be unravelled into a spectrum."



The installation of NIRSpec in the heart of the JWST had to be done with great care

Asteroid was "far larger than anything in the last billion years"

Evidence discovered of a massive Earth impact larger than Chicxulub

The asteroid that smashed into our planet 3.26 billion years ago is much larger than anything yet seen on Earth

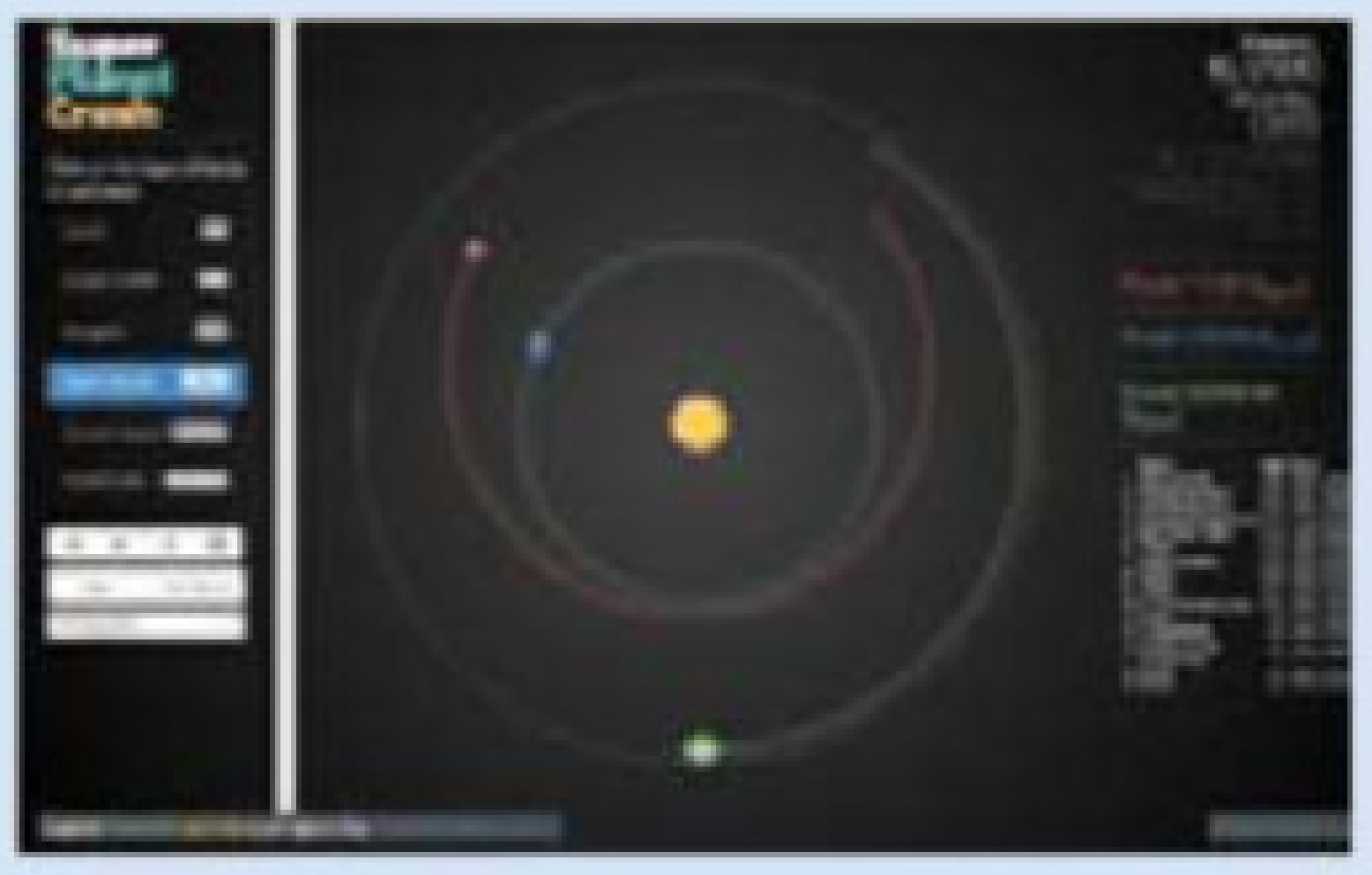
An asteroid estimated to be up to five-times larger than the one that supposedly wiped out the dinosaurs is thought to have slammed into our planet some 3.26 billion years ago.

The mammoth collision made Earth shudder for half an hour and created tsunamis thousands of times taller than the one following the Japanese earthquake in 2011. The evidence found by Donald Lowe of Stanford University doesn't come in the form of a crater - instead, it's in the shape of an ancient rock formation in south-eastern Africa.

The impactor is thought to have been somewhere between 37 and 58 kilometres (23 to 36 miles) wide, hitting our planet at 20 kilometres (12 miles) per second. "We knew it was big, but we didn't know how big," says Lowe. The impact sent debris into the atmosphere that circled the globe, with some finding its way into rocks thousands of miles away.

"The impact sent debris into the atmosphere that circled the globe"

What's more, there is also evidence for similar catastrophic impacts in South Africa and western Australia that occurred between 3.23 and 3.47 billion years ago, during the Late Heavy Bombardment period.



Super Planet Crash enables users to build planetary systems, accumulating points as they go. But be careful - any one of these planets could destroy it

Super Planet Crash: Angry Birds for astronomers

Forget *Candy Crush*, astronomers at UC Santa Cruz have developed *Super Planet Crash*, a game that enables you to build your own planetary system until it's destroyed, smashing up planets as it goes.

It's like *Angry Birds* for astronomers, but the aim of the game is to put planets into orbit around a star, racking up points as you go until a planet is added that inevitably obliterates the system. Hailed as quite an addictive game, the software code behind *Super Planet Crash* is actually the same that astronomers use to find worlds beyond our own Solar System.

This scientific software package, called Systemic Console, pulls planet discoveries out of the floods of data acquired by missions such as the Automated Planet Finder at Lick Observatory, giving a real-world feel to the game.

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A GRIPPING SPACE THRILLER FOR TODAY

In the style of the most action-packed James Bond movies, this novel launches you into a suspenseful story of international space intrigue and never lets up the pace.

Francis French, author,
In the Shadow of the Moon

International conspiracy hurls secret agent Peter Novak through another space-age thriller as he goes behind the scenes and back into orbit to thwart another Chinese plot.

Scott Gunnerson,
Florida Today

WHAT IF THE MOST EXPENSIVE AND AMBITIOUS STRUCTURE EVER ASSEMBLED, THE INTERNATIONAL SPACE STATION, WAS THREATENED?

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Charlie Duke
Apollo 16 Moonwalker

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Return to the Moon

No one has set foot on the Moon since 1972, but with commercial and government organisations restarting the space race, the way is being paved for humanity to make a long-awaited return to our constant orbital companion

Written by Laura Mears

In 1969, Neil Armstrong became the first human to step onto another world. Watched by half a billion people, this seminal event marked the culmination of a ten-year race with the Soviet Union and spurred three more years of manned lunar missions. The Apollo programme took 12 men to the Moon and returned hundreds of kilograms of rock home for study. However, since Eugene Cernan stepped back onto the lunar module in 1972, humanity hasn't returned to the Moon's surface.

Although the Soviet Union would send a few more unmanned lunar missions in the mid-1970s, after the Cold War ended the incentive to continue launching expensive missions was gone. The heavy-lift rockets required to propel a human crew, as well as all their life-support equipment, out of the atmosphere were very costly. In the wake of Apollo 13 and its on-board explosion there were also serious concerns over astronaut safety. The risk and expense outweighed any potential benefit and, during the 1980s, not a single spacecraft went to the Moon.

Today, advances in technology have reignited interest in the Moon and not only do the USA and Russia both have active missions examining the lunar surface, but over the last ten years they have been joined by craft from Japan, China and India.

The Moon is of particular interest to scientific study of the history of the Solar System. Since Earth formed 4.5 billion years ago, the surface has been constantly remodelled. Plate tectonics, volcanic activity, sediment deposition and erosion by water have changed the surface of our planet, burying evidence of the early Solar System. The Moon, however, is a time capsule. The lunar surface is static and craters dating back to the beginnings of the Solar System give us the opportunity to look back in time.

The information already gathered from the Moon has provided us with invaluable clues about our own history. Rocks recovered from impact craters during the Apollo missions revealed that shocked quartz is formed under the intense pressure of an asteroid collision. This discovery enabled us to link the presence of shocked quartz at the Cretaceous-Tertiary boundary inside the Earth's crust with a meteorite impact, providing evidence to support the theory that a huge space rock killed the dinosaurs.

Interest in the geology of the Moon grew and in 2008 India launched its first scientific mission, Chandrayaan-1, into its orbit. The craft, a cuboidal, solar-powered orbiter, was designed to generate a three-dimensional map of the entire surface of the Moon and identify the positions of valuable mineral deposits. A follow-up mission, Chandrayaan-2, is planned for late-2016 or early-2017 and will include a lander, with a rover set to investigate the composition of the landing site. This will make India the fourth nation to soft-land a craft on the Moon, paving the way for future exploratory ventures. The Russian

Federal Space Agency is also very interested in learning more about the history of the Moon and the Luna-Glob 1 mission, also launching in 2016, will use ground-penetrating sensors to strike the surface in order to detect seismic activity.

Not only could lunar rocks provide information about the history of our Solar System, there is also much to be learnt about our own relationship with the Moon itself. Since the late-1950s, humanity has bombarded the Moon with exploratory craft and the remnants of impactors, landers and rovers remain on the surface. These relics are not only a key part of human history, but analysing their condition after 40 or more years on the lunar surface could offer valuable information for future equipment design.

Buzz Aldrin once said, "We've done the Moon", but in fact we've barely scratched the surface. The surface area of our natural satellite is approximately equal to North and South America combined and we've only explored a tiny fraction of it. The Google Lunar XPRIZE is offering $20 million (£12 million) to the first private team to land a robot on the surface of the Moon, explore for 500 metres (1,640 feet) in any direction and then send high-definition footage of this achievement home to Earth. Extra money will be awarded if the team manages to land near a heritage site – particularly one of the Apollo landers.

The Moon itself is a valuable resource, so both government space agencies and private companies are interested in utilising its untapped potential. Rock samples collected by Neil Armstrong revealed that lunar soil contains helium-3. This rare isotope of helium is a potential fuel source for a clean nuclear fusion reactor. It could also be used in medical technology, producing isotopes.

Many teams competing for the Google Lunar XPRIZE are also interested in the potential for

> "There is also much to be learnt about our relationship with the Moon"

Since Apollo 11 touched down on the Moon in 1969, only 12 people have visited the satellite

Luna 2

Surveyor 1

Apollo 11

Apollo 11

Apollo 11

Apollo 11

Apollo 11

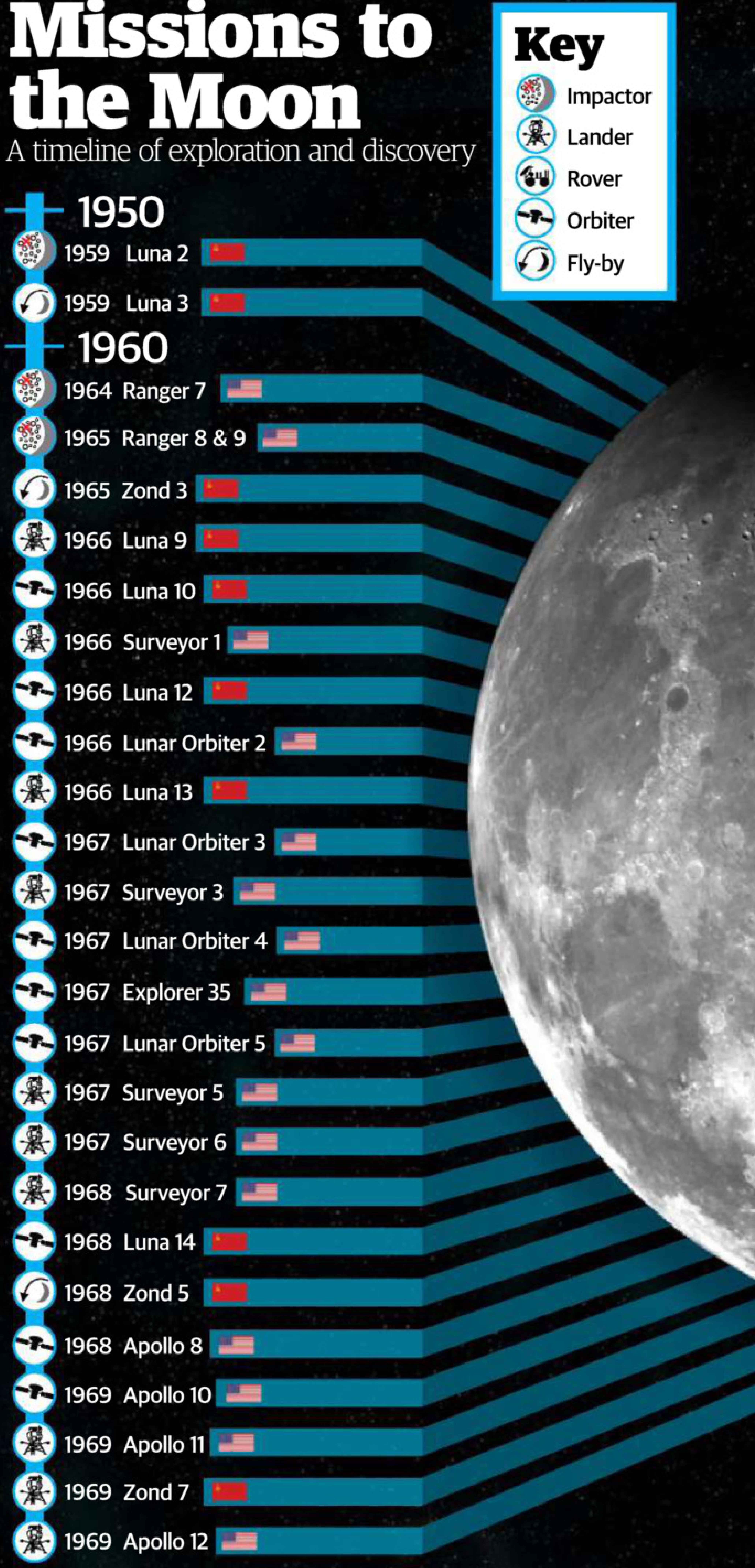
Apollo 11

Apollo 11

Apollo 12

Missions to the Moon

A timeline of exploration and discovery



Key

- Impactor
- Lander
- Rover
- Orbiter
- Fly-by

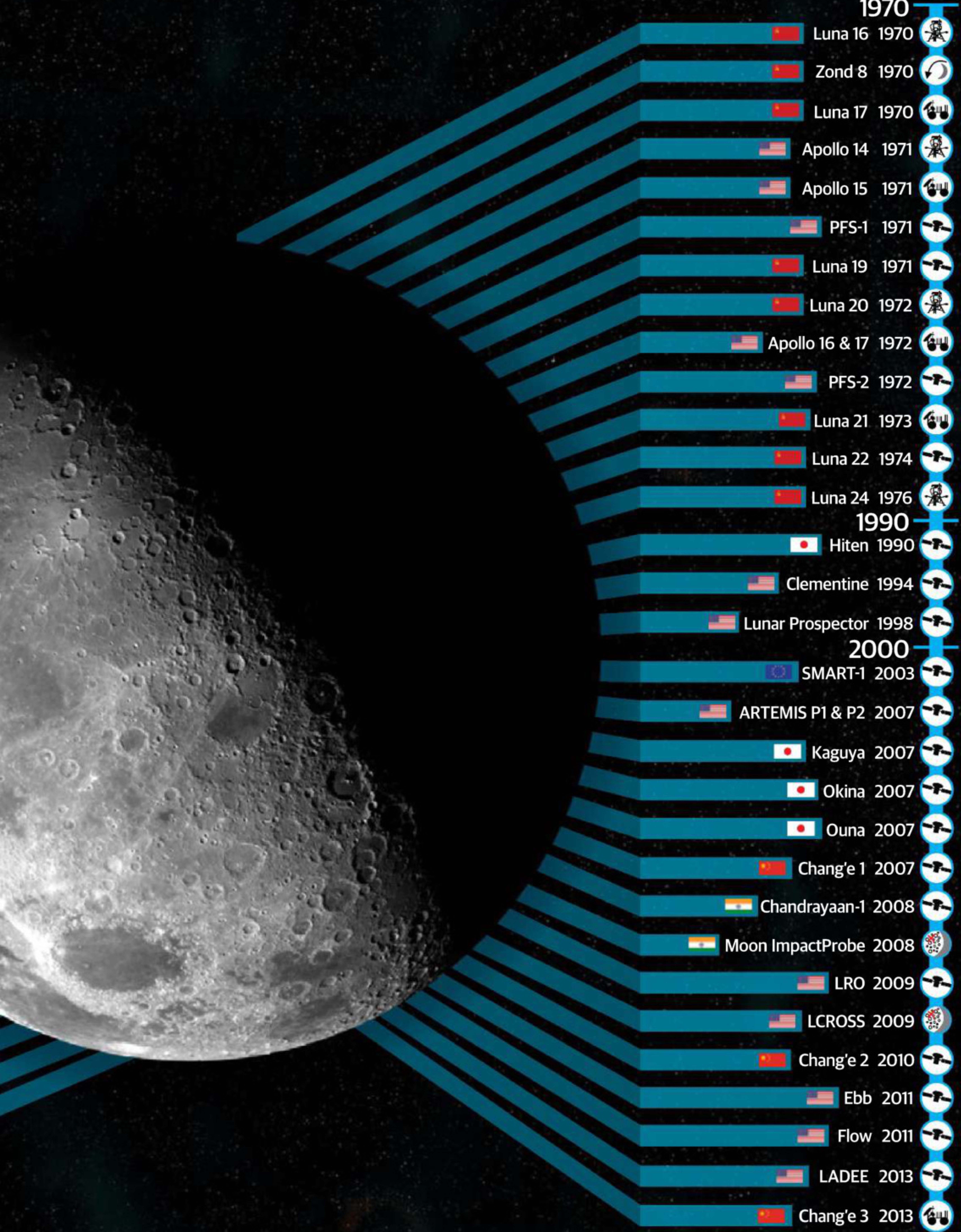
1950

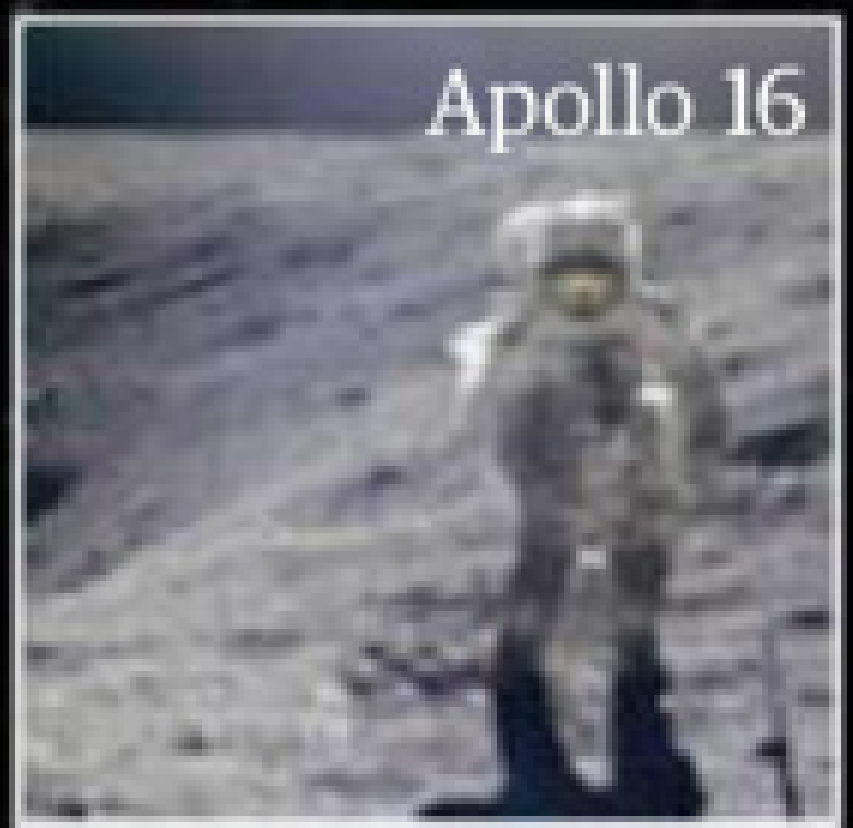
1959 Luna 2
1959 Luna 3

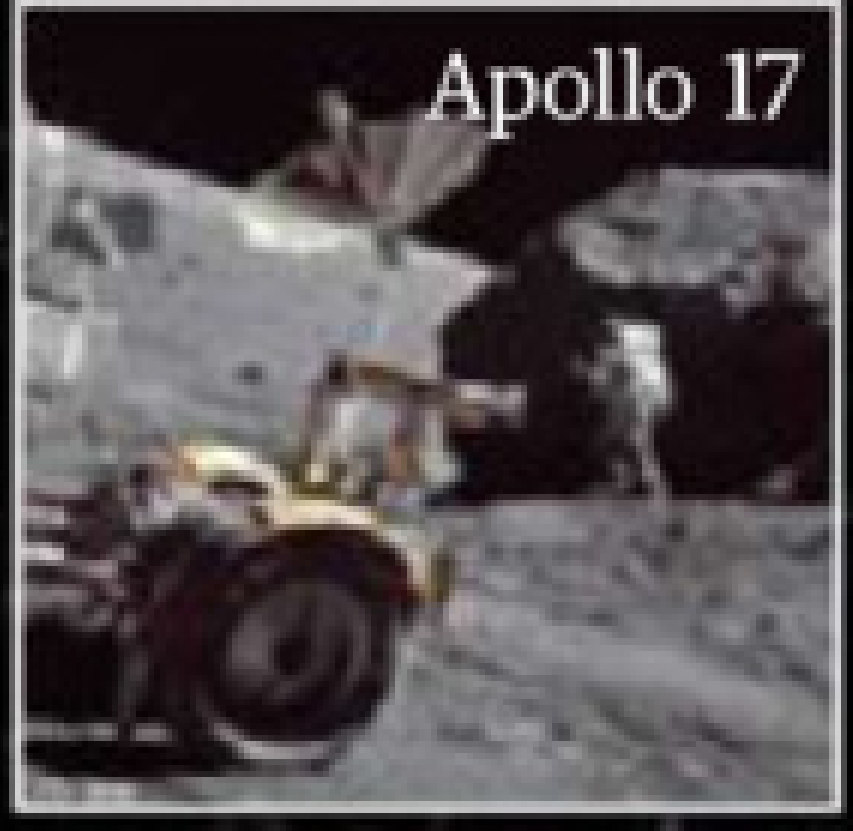
1960

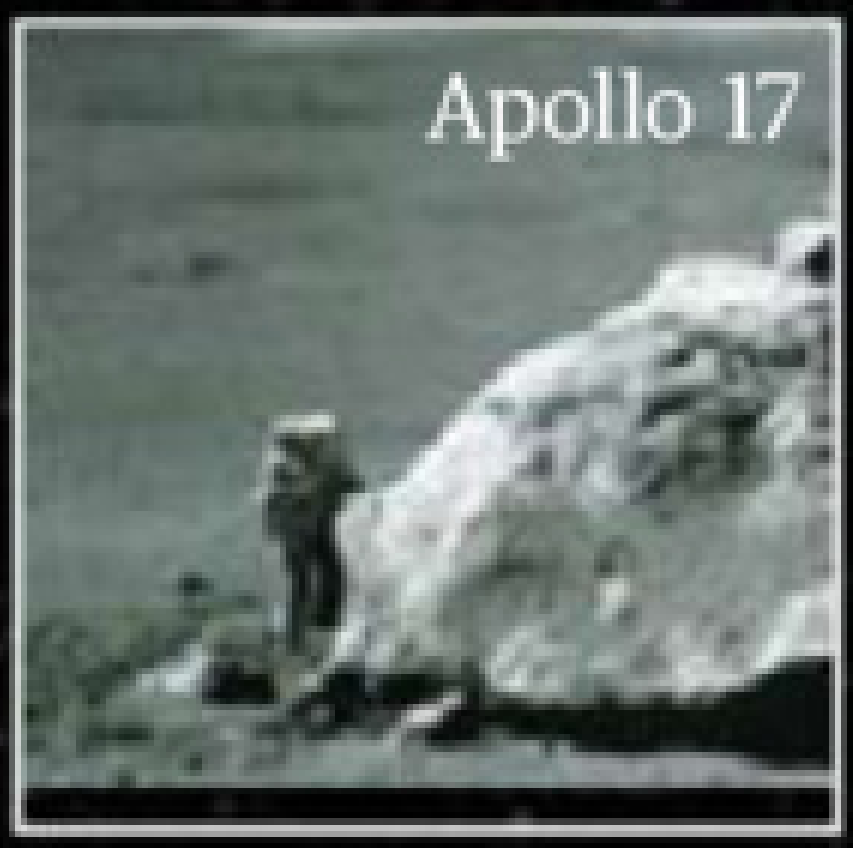
1964 Ranger 7
1965 Ranger 8 & 9
1965 Zond 3
1966 Luna 9
1966 Luna 10
1966 Surveyor 1
1966 Luna 12
1966 Lunar Orbiter 2
1966 Luna 13
1967 Lunar Orbiter 3
1967 Surveyor 3
1967 Lunar Orbiter 4
1967 Explorer 35
1967 Lunar Orbiter 5
1967 Surveyor 5
1967 Surveyor 6
1968 Surveyor 7
1968 Luna 14
1968 Zond 5
1968 Apollo 8
1969 Apollo 10
1969 Apollo 11
1969 Zond 7
1969 Apollo 12

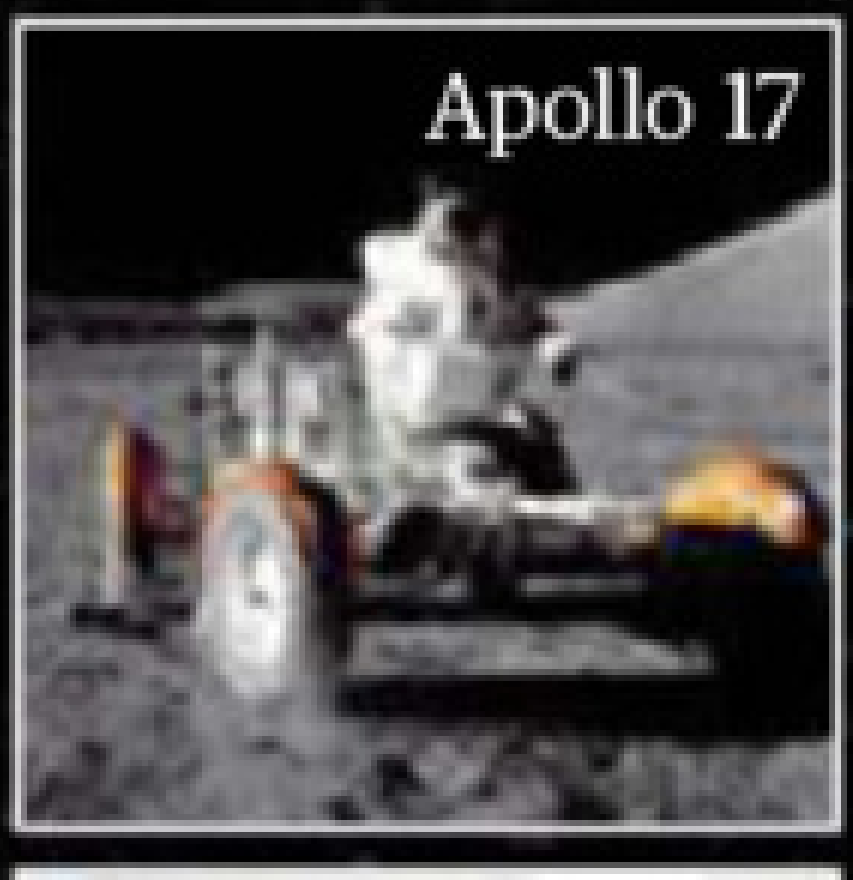
Return to the Moon





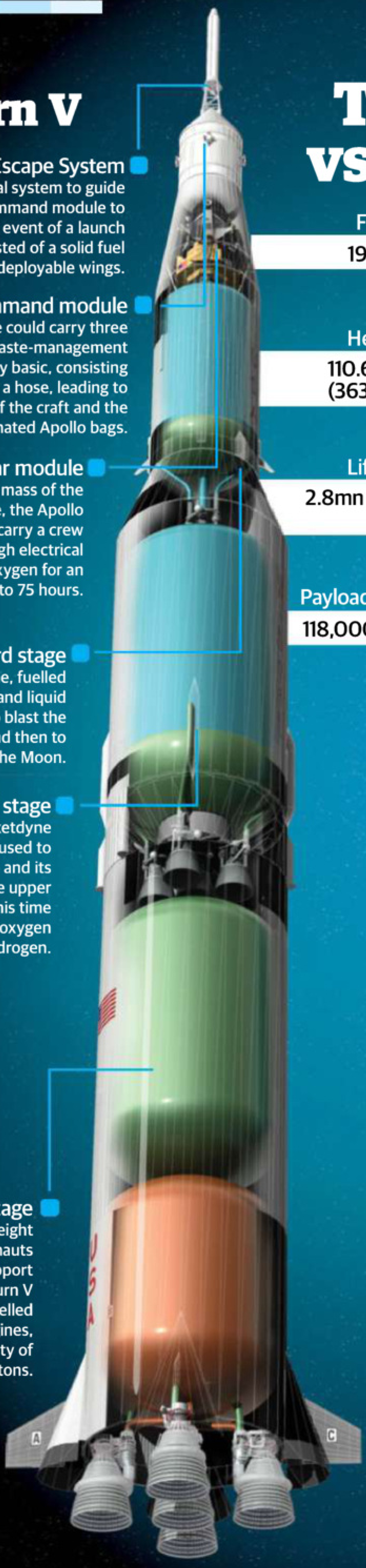






Then vs now

	Saturn V	SLS
First flight	1967	2017
Height overall	110.6m (363ft)	Up to 117m (384ft)
Liftoff weight	2.8mn kg	Up to 2.9mn kg
Payload to LEO	118,000kg	Up to 130,000kg



Saturn V

Launch Escape System
The original system to guide the command module to safety in the event of a launch failure consisted of a solid fuel rocket with deployable wings.

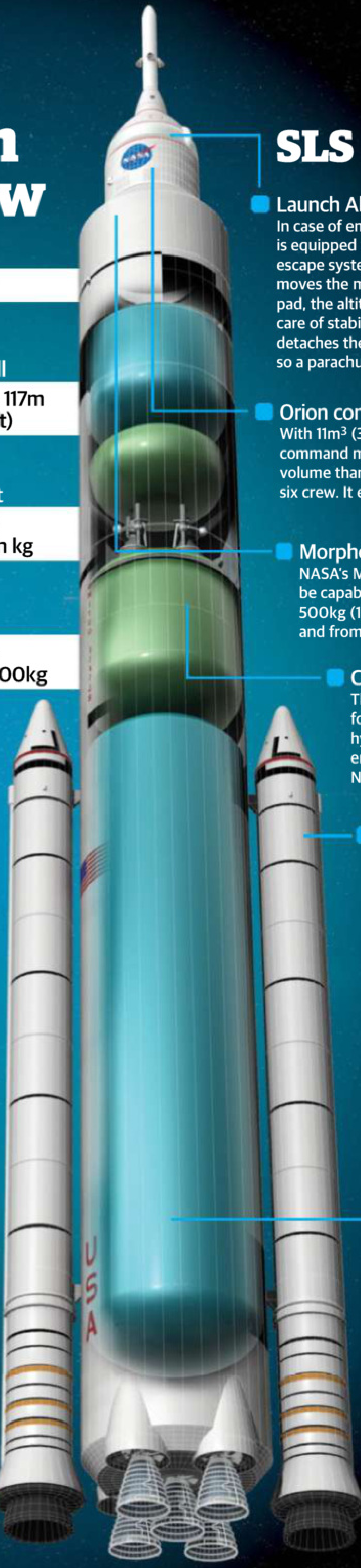
Command module
The command module could carry three crew members. The waste-management system was incredibly basic, consisting of little more than a hose, leading to a vent on the side of the craft and the much-hated Apollo bags.

Apollo lunar module
At around half the mass of the command module, the Apollo lunar module could carry a crew of two, with enough electrical storage, coolant and oxygen for an operational time of up to 75 hours.

S-IVB third stage
A single J-2 engine, fuelled by liquid oxygen and liquid hydrogen, was used to blast the rocket into orbit and then to set the trajectory to the Moon.

S-II second stage
A further five Rocketdyne J-2 engines were used to accelerate Apollo and its crew through the upper atmosphere, this time powered by liquid oxygen and liquid hydrogen.

S-IC first stage
In order to lift the weight of human astronauts and their life-support equipment, Saturn V had kerosene-fuelled Rocketdyne F-1 engines, with a lift capability of 118 metric tons.



SLS

Launch Abort System
In case of emergency at launch, Orion is equipped with a three-rocket launch escape system. The primary motor moves the module clear of the launch pad, the altitude control motor takes care of stability and the jettison motor detaches the LAS from the crew module, so a parachute can be deployed.

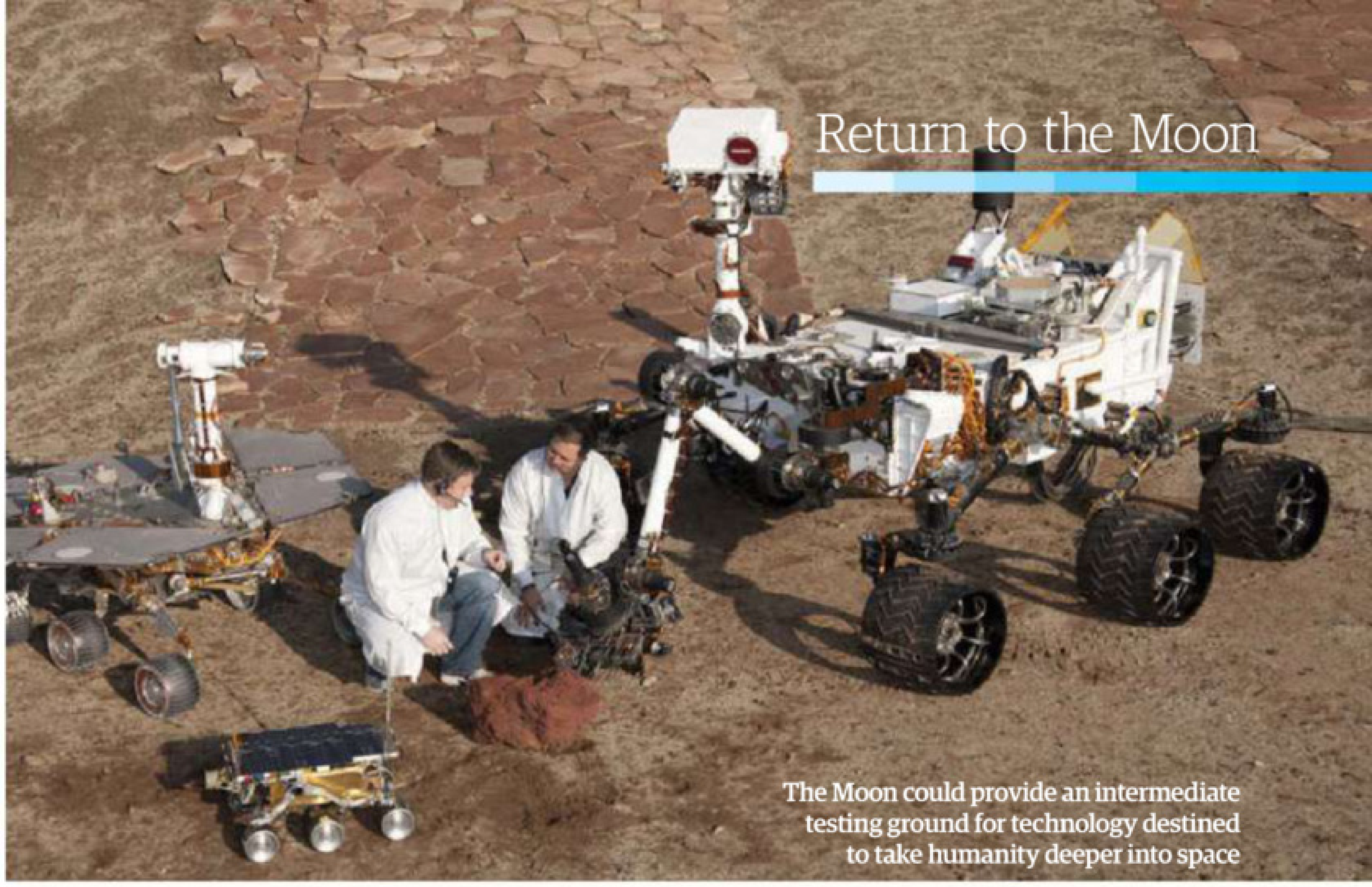
Orion command module
With 11m³ (388ft³) of space, the Orion command module has 50 per cent more volume than Apollo and can carry up to six crew. It even has a toilet on board.

Morpheus lander
NASA's Morpheus lander will be capable of carrying up to 500kg (1,100lb) of cargo to and from the lunar surface.

Core stage
The main thrust comes from four liquid oxygen and liquid hydrogen-fuelled RS-25D/E engines, modified from NASA's retired Space Shuttle.

Solid rocket boosters
For the first two minutes, rocket boosters will provide extra thrust. Early configurations will carry modified Space Shuttle boosters, enabling the SLS to lift around 70 tons.

Block II configuration
A more-powerful Block II configuration of the SLS will be able to lift up to 130 tons, 12 tons more than the Saturn V. NASA is holding an Advanced Booster Competition to develop the technology to support a heavier lift vehicle.



The Moon could provide an intermediate testing ground for technology destined to take humanity deeper into space

extracting water. NASA's Lunar Reconnaissance Orbiter (LRO) found hydrogen in impact sites, while the Lunar Crater Observation and Sensing Satellite (LCROSS) mission in 2009 detected water ice and water vapour in the craters.

Not only could helium-3 be used as a source of water, but it could also be split into its component parts – hydrogen and oxygen – for fuel and air supplies for astronauts. Water is heavy, so launching large quantities into space is costly, but this precious resource could serve as a refuelling station in space.

Rocks on the surface could also provide a valuable source of construction materials, either for return to Earth, or for building in space. Much like transporting water, moving materials into space would require powerful rockets. The lunar surface contains silicon, aluminium and titanium, plus many rare metals – some of the raw materials required to make solar panels. It's even been proposed that the Moon could be converted into a solar farm to harness energy.

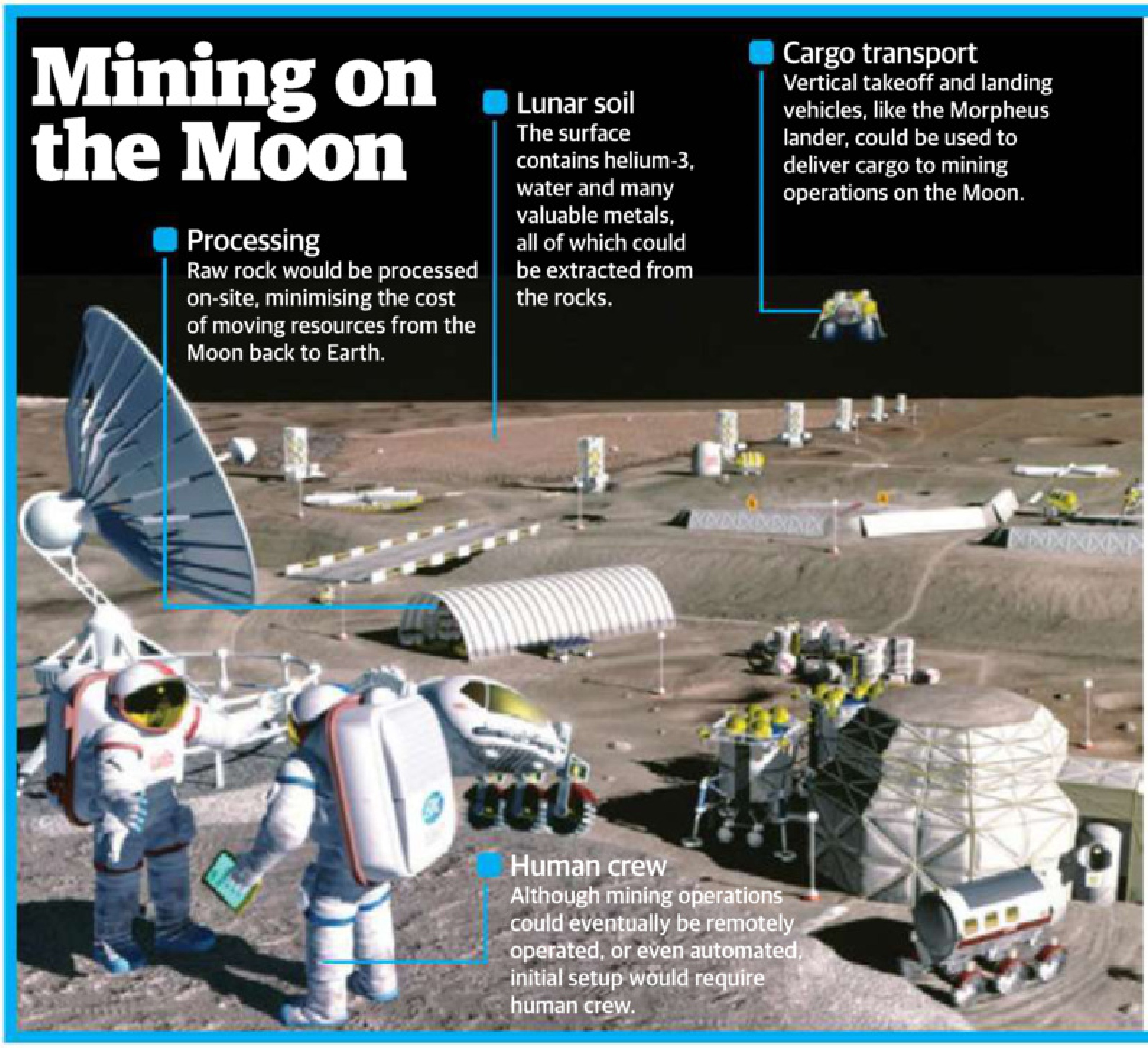
China's ambitious Chang'e programme saw the first soft landing on the surface of the Moon since 1976, and has an ultimate goal of setting up a lunar base and exploiting its natural resources. The Chang'e 3 lander delivered the Yutu ('Jade Rabbit') rover to the surface of the Moon in 2013. It carries a spectrometer, along with a ground-penetrating radar, which together are being used to measure the structure and depth of the lunar soil, alongside identifying the locations of potential resources. A follow-up mission – Chang'e 5 – is scheduled to launch in 2017, with the intention of bringing two kilograms (4.4 pounds) of lunar rock home for study. The Luna-Grunt missions, headed by the Russian Federal Space Agency, meanwhile, due to launch in 2020 and 2021, will also bring Moon rock samples back to Earth.

Maps of the lunar surface and detailed information about rock composition gathered by government-funded projects, as well as private ventures, could pave the way for a lunar base. Energy derived from solar arrays or helium-3 fusion could be used to charge as well as refuel spacecraft using hydrogen and oxygen obtained from lunar water. Astronauts could also replenish supplies of oxygen and water.

Establishing such an outpost is a goal shared by private companies and some national space

> "Rocks on the surface could also provide a source of construction materials for building in space"

Mining on the Moon



Processing
Raw rock would be processed on-site, minimising the cost of moving resources from the Moon back to Earth.

Lunar soil
The surface contains helium-3, water and many valuable metals, all of which could be extracted from the rocks.

Cargo transport
Vertical takeoff and landing vehicles, like the Morpheus lander, could be used to deliver cargo to mining operations on the Moon.

Human crew
Although mining operations could eventually be remotely operated, or even automated, initial setup would require human crew.

Helium-3 is a light isotope of helium, with one less neutron than the more-common helium-4. The resource is produced in the Sun and transmitted through space alongside solar wind. It's rare on Earth because we are shielded by the magnetosphere (only about 15 tons exist on the entire planet), but the Moon has no such protection, so lunar rock is thought to contain between 1 and 5 million tons.

Helium-3 could potentially be used in two types of nuclear fusion reaction: the first with deuterium to produce helium and a proton; the second with itself to form helium and two protons. These protons could be used to make clean energy using an electromagnetic field, with the reaction producing no dangerous neutrons or radioactive waste.

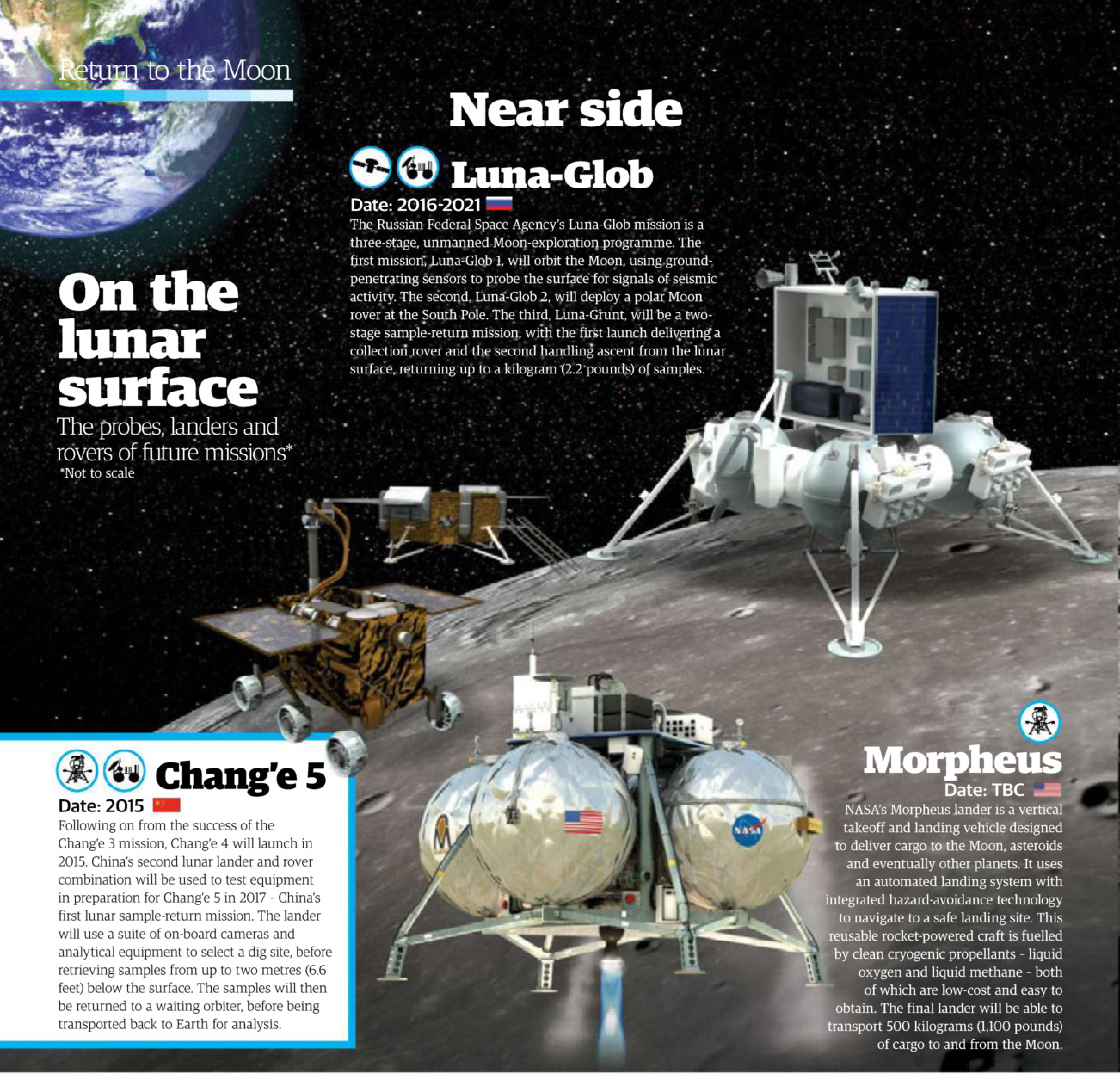
The technology to do this hasn't yet been developed, however, and although helium-3 fusion has been achieved on Earth, it has yet to produce appreciable amounts of energy. It's estimated that with a development budget of around £8.9 billion ($15 billion), a reactor could be developed and a mining operation could begin on the Moon.

The concentration of helium-3, although higher than on Earth, still isn't huge, so large amounts of rock would need to be excavated in order to extract the material. This process itself would be relatively simple, as the rocks could be heated to liberate trapped gases, which could then be separated out. A single shuttle full of helium-3 could power a big city for an entire year.

On the lunar surface

The probes, landers and rovers of future missions*

*Not to scale



Near side

Luna-Glob

Date: 2016-2021

The Russian Federal Space Agency's Luna-Glob mission is a three-stage, unmanned Moon-exploration programme. The first mission, Luna-Glob 1, will orbit the Moon, using ground-penetrating sensors to probe the surface for signals of seismic activity. The second, Luna-Glob 2, will deploy a polar Moon rover at the South Pole. The third, Luna-Grunt, will be a two-stage sample-return mission, with the first launch delivering a collection rover and the second handling ascent from the lunar surface, returning up to a kilogram (2.2 pounds) of samples.

Chang'e 5

Date: 2015

Following on from the success of the Chang'e 3 mission, Chang'e 4 will launch in 2015. China's second lunar lander and rover combination will be used to test equipment in preparation for Chang'e 5 in 2017 – China's first lunar sample-return mission. The lander will use a suite of on-board cameras and analytical equipment to select a dig site, before retrieving samples from up to two metres (6.6 feet) below the surface. The samples will then be returned to a waiting orbiter, before being transported back to Earth for analysis.

Morpheus

Date: TBC

NASA's Morpheus lander is a vertical takeoff and landing vehicle designed to deliver cargo to the Moon, asteroids and eventually other planets. It uses an automated landing system with integrated hazard-avoidance technology to navigate to a safe landing site. This reusable rocket-powered craft is fuelled by clean cryogenic propellants – liquid oxygen and liquid methane – both of which are low-cost and easy to obtain. The final lander will be able to transport 500 kilograms (1,100 pounds) of cargo to and from the Moon.

agencies, including China, but another major hurdle to overcome is sending humans back to the Moon. NASA has developed a modern heavy-lift rocket and manned spacecraft to replace the original Saturn V and Apollo, but has abandoned all plans for another manned mission to the Moon, in favour of projects to take human crew to the surface of an asteroid and eventually to Mars.

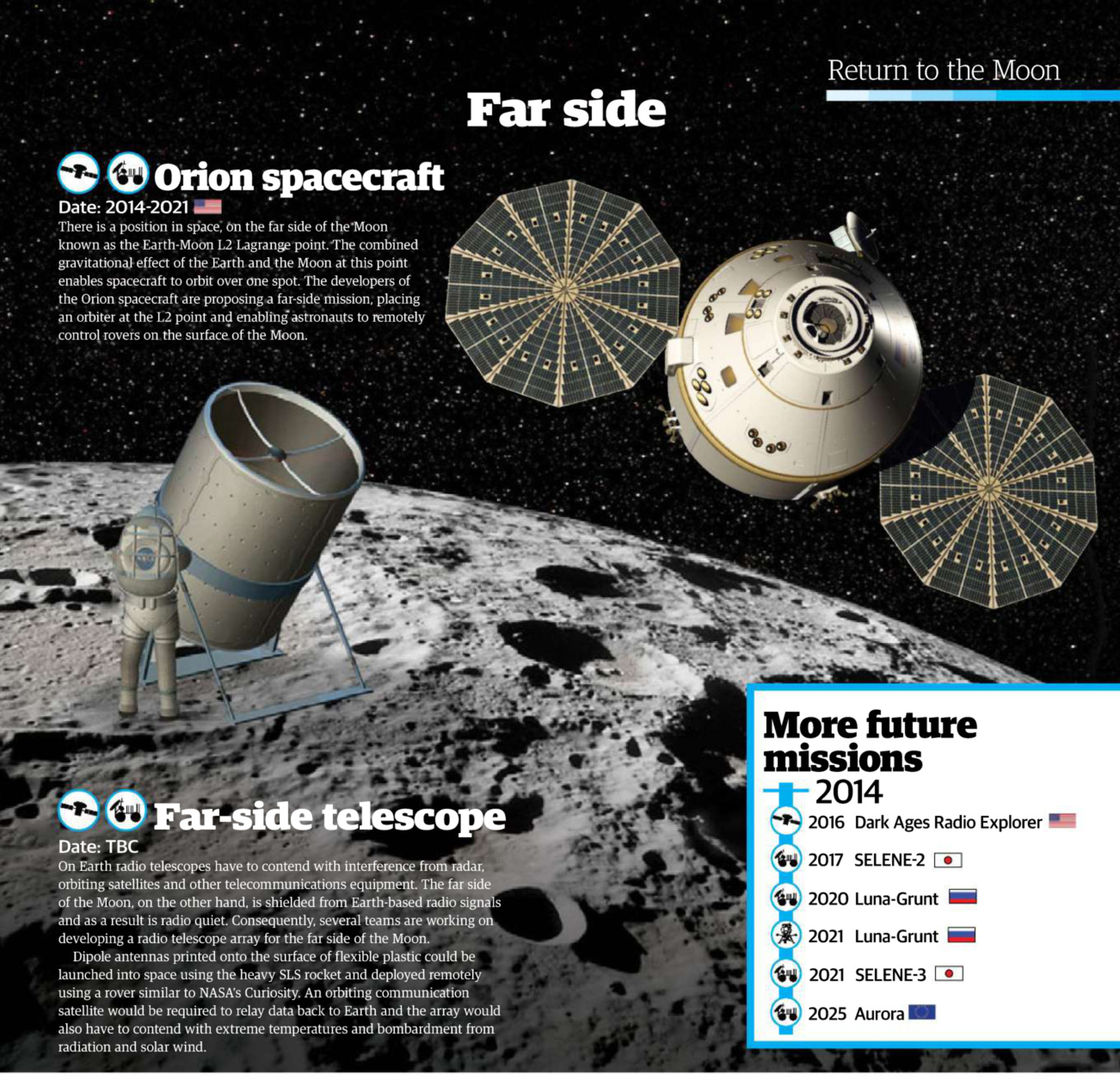
At this point the longest a human has ever spent on the surface of another world is three days. In order to send a worthwhile manned mission to Mars, this timeframe will need to be extended to weeks, if not months. Not only does equipment need to be developed and tested, but biological and psychological factors also need to be taken into account. Experimentation can be done on Earth, such as the 17-month simulated mission to Mars carried out in Russia in 2013 to study the effects of a manned Mars mission on the human body. However, the more manned missions that go to the Moon, the more information we will have to guide us when planning missions to Mars and beyond.

The Moon is also a potential location for an extraterrestrial scientific base. The Solar System is bathed in radiation signals released just after the Big Bang. Before the first stars, neutral hydrogen gas was distributed evenly across the universe. Small pockets of increased density went on to form the seeds of stars and the UV light they would make ionised the remaining hydrogen, stripping it away.

Radiation signals from this hydrogen still reach Earth today, enabling us to look back in time. However, because of red-shift, by the time the signals get here, they are in the low-frequency radio range and our own telecommunications interfere with the signal. By setting up an array of radio telescopes on the far side of the Moon, research teams like the Lunar University Network for Astrophysics Research (LUNAR) hope to bypass this interference.

The major challenge is developing a telescope array light enough to launch to the Moon and simple enough to be deployed by a robot. By printing dipoles onto flexible polyimide film, a rover similar to NASA's Curiosity could be used to unroll the array across the surface of the Moon.

Far side



Orion spacecraft

Date: 2014-2021 🇺🇸

There is a position in space, on the far side of the Moon known as the Earth-Moon L2 Lagrange point. The combined gravitational effect of the Earth and the Moon at this point enables spacecraft to orbit over one spot. The developers of the Orion spacecraft are proposing a far-side mission, placing an orbiter at the L2 point and enabling astronauts to remotely control rovers on the surface of the Moon.

Far-side telescope

Date: TBC

On Earth radio telescopes have to contend with interference from radar, orbiting satellites and other telecommunications equipment. The far side of the Moon, on the other hand, is shielded from Earth-based radio signals and as a result is radio quiet. Consequently, several teams are working on developing a radio telescope array for the far side of the Moon.

Dipole antennas printed onto the surface of flexible plastic could be launched into space using the heavy SLS rocket and deployed remotely using a rover similar to NASA's Curiosity. An orbiting communication satellite would be required to relay data back to Earth and the array would also have to contend with extreme temperatures and bombardment from radiation and solar wind.

More future missions

2014

2016	Dark Ages Radio Explorer	🇺🇸
2017	SELENE-2	🇯🇵
2020	Luna-Grunt	🇷🇺
2021	Luna-Grunt	🇷🇺
2021	SELENE-3	🇯🇵
2025	Aurora	🇪🇺

> "The major challenge is developing a telescope array light enough to launch to the Moon and simple enough to be deployed by a robot"

In preparation for such a project, the Dark Ages Radio Explorer (DARE) project, an orbiter proposed for launch in 2016, will enter low-inclination orbit around the Moon in order to gather radio data from the quiet zone. This orbiter will be followed in 2018 by a private collaboration between the not-for-profit International Lunar Observatory Association (ILOA), and space courier Moon Express, which intends to place a two-metre (6.6-foot) radio antenna at the lunar South Pole. This location is less well-shielded from radio interference, but offers a direct line of sight back to Earth for communication and could be a major stepping-stone towards setting up a scientific station on the lunar surface.

A lunar base might seem like a far-off dream, but the involvement of private enterprise could drastically reduce setup costs, particularly as more innovative technologies are developed. Lunar tourism could eventually be used to offset the cost of transporting materials to and from the Moon, with equipment tagged onto commercial space flights. NASA's new Lunar CATALYST project hopes to team up with commercial interests, developing a lunar lander that could be used both to deliver commercial payloads to the Moon and aid scientific endeavours.

Returning to the Moon is another small step. All of the technology is already there, but the potential leap that it would enable us to make in terms of gaining a foothold off Earth could be huge. ■

The Google Lunar XPRIZE aims to encourage innovations in furthering Moon exploration

Why should we go back?

Andrew Barton, director of technical operations for the Google Lunar XPRIZE, on the future of lunar exploration

What are the potential benefits of returning to the Moon?

In the near-term there are many scientific questions about the Moon, the Earth and the rest of the Solar System that can only be answered by sending instruments to the lunar surface. Despite being lifeless, the Moon might hold scientific secrets that can help answer questions about the origin of life. In the longer term the minerals and resources on the Moon could be used to support astronauts in space, satellites in orbit and even industry here on Earth. One of the defining characteristics of the human species is a never-ending drive to expand our horizons, to explore and to learn. The Moon is a continent-sized area begging to be explored and once reliable and cost-effective transportation systems exist to access its surface, there will be countless people wanting to go and see what they can do there.

Could the Moon provide a platform for travel farther into space?

There is strong evidence that a quantity of water is present in the form of ice that's frozen inside permanently shadowed craters near the poles of the Moon. If that water can be successfully extracted, it would be an ideal rocket fuel to power ships exploring the Moon or other destinations in the Solar System. Earth's gravity well is approximately 20 times deeper than the Moon's; that means that any rocket fuel located in the vicinity of the Moon is far more valuable than the equivalent amount on Earth.

What are the major technical challenges involved in manned missions to the Moon?

Sending humans to the Moon is a massive undertaking, even with modern technology. The list of challenges includes life support systems, water, food, sanitation, radiation, medical needs, communications - the list goes on. All of the equipment and consumables required to do those things need to be launched from Earth and transported to the Moon. Weight is at an absolute premium when transporting things to the lunar surface, so there's a strong drive to reduce the mass of all those things, but if you reduce it too far you run the risk of catastrophic equipment failures or running out of critical supplies. Balancing all those needs requires a lot of effort and will also need a lot of new technologies.

What future do you see for the Moon? Is a lunar base likely?

Just like the exploration programme in Antarctica, scientists want to establish bases on the Moon. After the technical challenges of the Google Lunar XPRIZE are overcome, small lunar landers will be available as a delivery service to take equipment to the Moon. The stage will then be set for an incremental growth in the size of those lunar landers. Simultaneously, the costs of launch from Earth's surface will drop, especially if companies like SpaceX manage to make a fleet of reusable rockets. Lunar bases will most likely be established once the transportation systems are developed far enough to provide safe and affordable access to the surface for astronauts and sufficiently large cargo to support their life there.

What role do you think private companies will play in future exploration of the Moon?

In the Apollo era private companies helped explore the Moon by undertaking government contracts. Today companies are starting to use private risk capital to finance the development of Google Lunar XPRIZE missions and other advanced space projects. In the future, private companies will play an even more important role as financiers, operators of transportation and other services needed to explore the Moon. Governments will continue to play a role, but over time their role will be less of a financial one and more of a regulatory one.

> "Sending humans to the Moon is a massive undertaking, even with modern technology"

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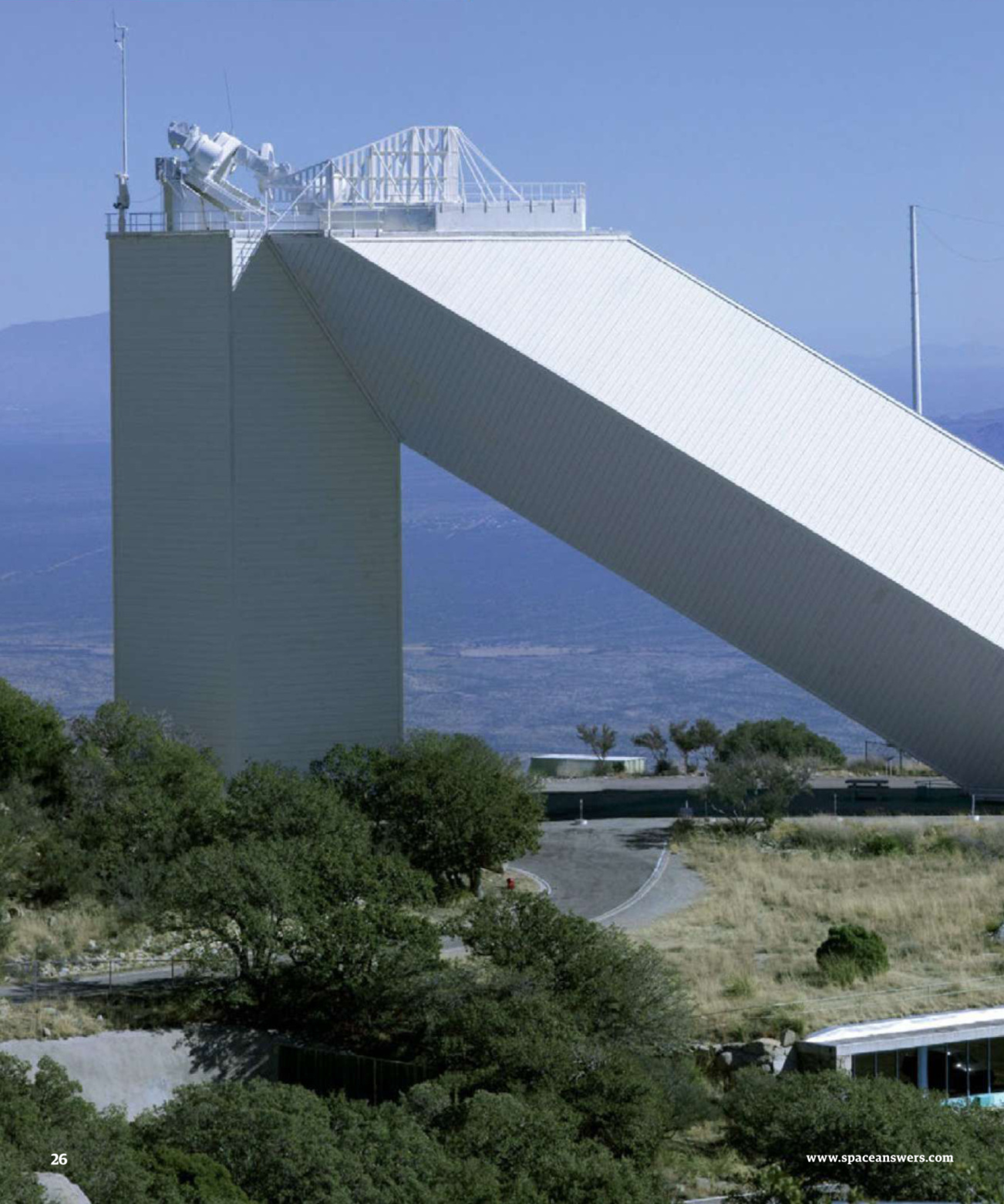
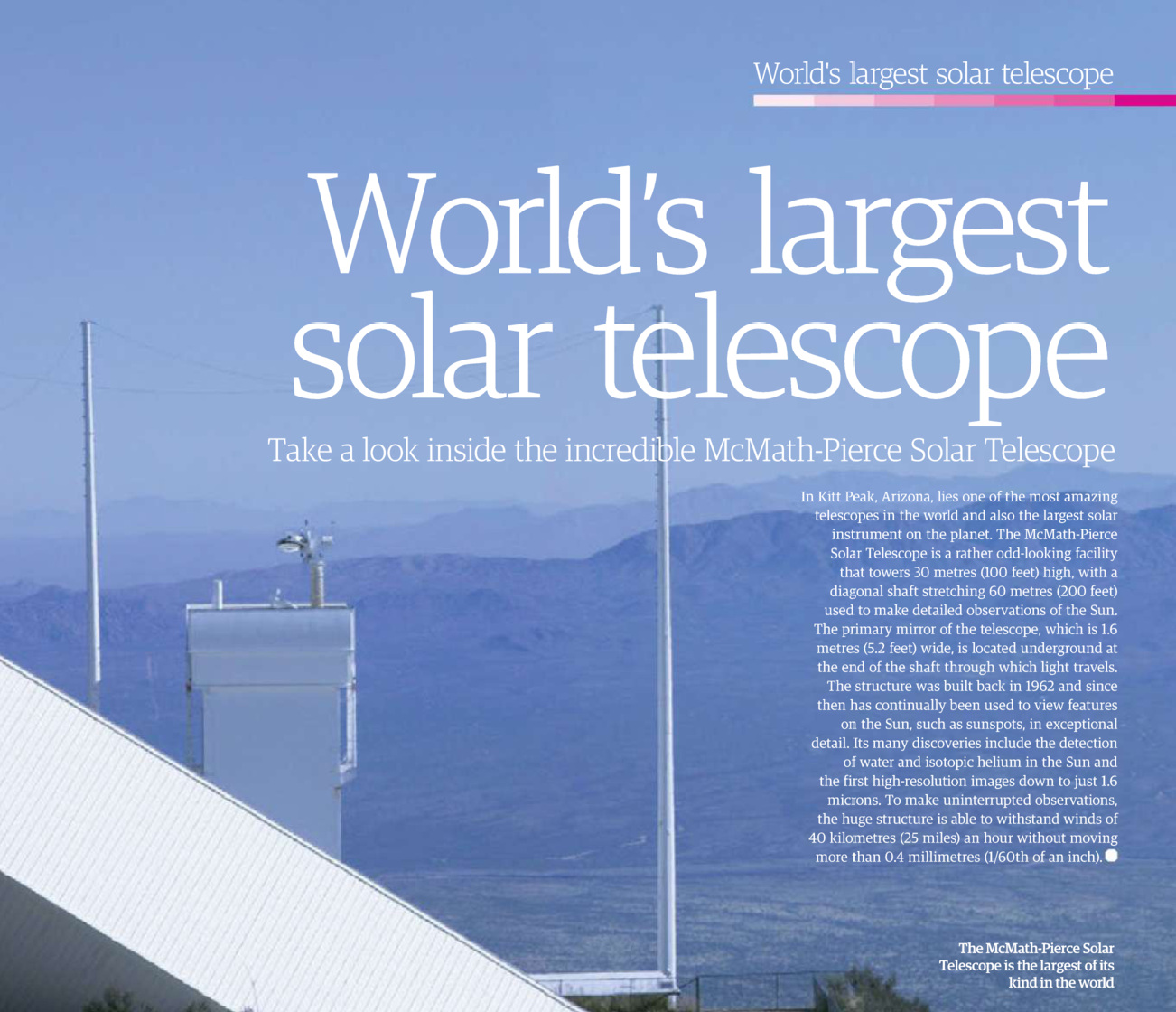


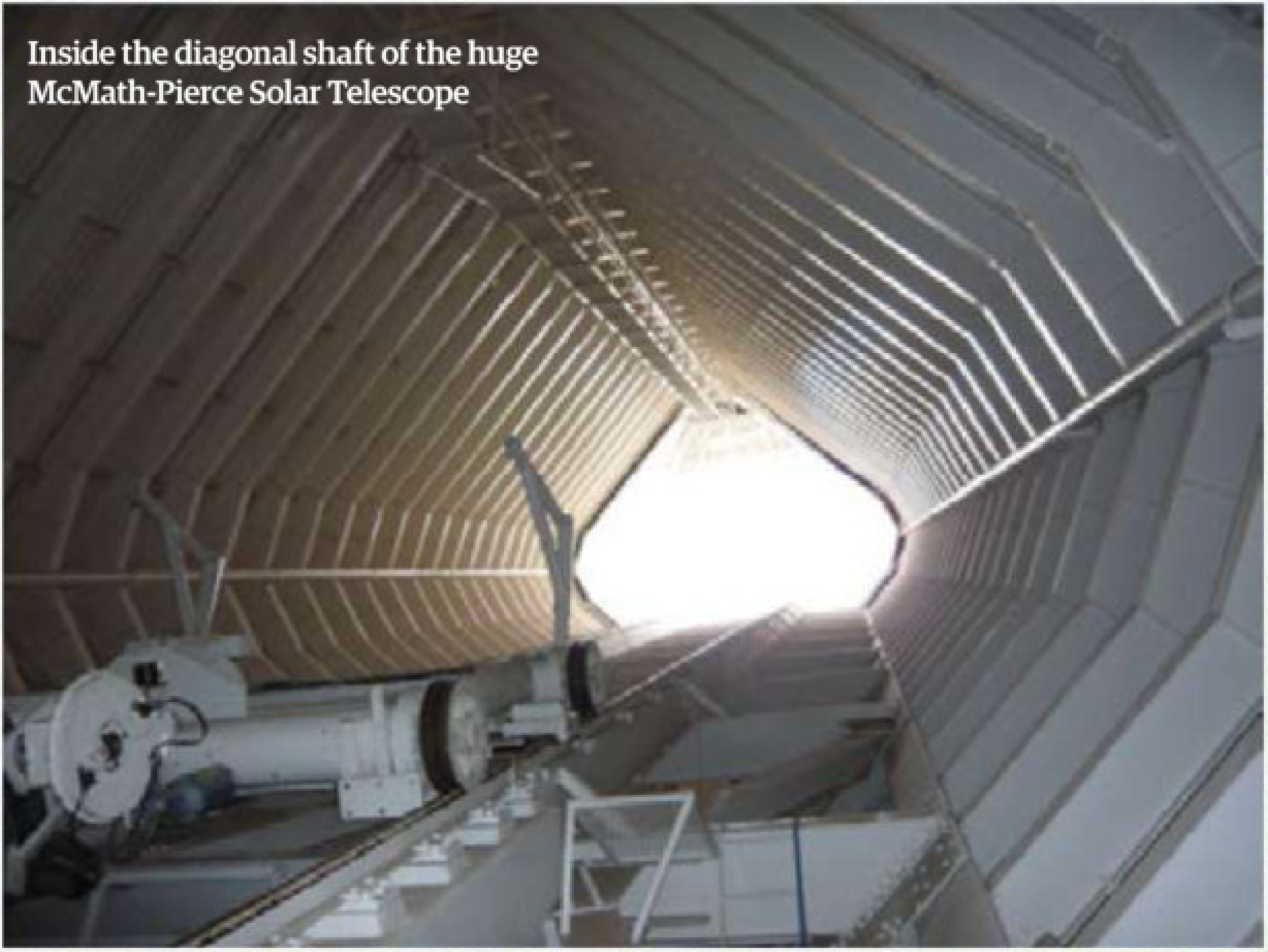
World's largest solar telescope

Take a look inside the incredible McMath-Pierce Solar Telescope

In Kitt Peak, Arizona, lies one of the most amazing telescopes in the world and also the largest solar instrument on the planet. The McMath-Pierce Solar Telescope is a rather odd-looking facility that towers 30 metres (100 feet) high, with a diagonal shaft stretching 60 metres (200 feet) used to make detailed observations of the Sun. The primary mirror of the telescope, which is 1.6 metres (5.2 feet) wide, is located underground at the end of the shaft through which light travels. The structure was built back in 1962 and since then has continually been used to view features on the Sun, such as sunspots, in exceptional detail. Its many discoveries include the detection of water and isotopic helium in the Sun and the first high-resolution images down to just 1.6 microns. To make uninterrupted observations, the huge structure is able to withstand winds of 40 kilometres (25 miles) an hour without moving more than 0.4 millimetres (1/60th of an inch).



The McMath-Pierce Solar Telescope is the largest of its kind in the world



Inside the diagonal shaft of the huge McMath-Pierce Solar Telescope

© NOAO/AURA/NSF

Hidden planets IN THE SOLAR SYSTEM

How well do we really know our Solar System? Some experts think there are other worlds that could be - or have been - lurking in the shadows, but where are they?

Written by Gemma Lavender

We know that there are other worlds out there far beyond the eight planets of our Solar System, but what if someone told you that there could be celestial objects quite a few light years closer? These are worlds that are hidden away in our very own Solar System - an unacknowledged part of the family that orbits the Sun.

Granted, we seem to have the basic layout of our Solar System pegged. Four terrestrial planets are cut off from the monstrous outer objects by the Asteroid Belt, while even farther away are the icy denizens of the Kuiper Belt. Our neighbourhood is further encased by the Oort Cloud, a spherical form that's chock-a-block with comets. With this in mind, the mere suggestion of hidden planets seems a bit far-fetched. After all, we would surely have found them by now, wouldn't we?

Well, perhaps not, as there's still some odd behaviour in the Solar System that leaves astronomers flummoxed. While some planets may have existed long ago in the past and were lost to some unforgiving force aeons ago, traces of their existence might still remain. Our solar neighbourhood's traumatic past - the so-called Late Heavy Bombardment period - could all be down to the influence of planets that no longer exist. What's happening right now in the Solar System could be down to some world - invisible to us - having fun and games with other objects in the astronomical local vicinity, revealing tantalising clues to its existence in the process.

It was during the 1850s that the first of these elusive planets, later named Vulcan, was thought to have been spotted. The theory of this missing planet was postulated by French mathematician Urbain Le Verrier, who spent much of his time studying the orbit of innermost planet Mercury. He found that, from observation, the planet's orbit differed by around 43 arcseconds every century compared with what was predicted by the classical mechanics of Johannes Kepler and Isaac Newton. The orbit was precessing and Le Verrier thought that some undetected world located between Mercury and the Sun was to blame.

In 1859 Le Verrier received a letter from an amateur astronomer stating that the planet, which seemed to be causing some fuss among many observers, had been found. An amateur, Edmond Lescarbault had been using his four-inch refractor when he noticed a small black dot moving across the face of the Sun. Having witnessed Mercury move across our star previously in 1845, Lescarbault suspected that what he had witnessed was a new body: the fabled Vulcan.

Satisfied that Lescarbault had detected the inner planet, Le Verrier made an announcement of its discovery in 1860. Other astronomers, unconvinced, questioned the existence of Vulcan but Le Verrier wasn't to be swayed and died in 1877 certain to the end that Vulcan had been found. It wasn't until some time later that general relativity was ultimately able to explain the changes in Mercury's orbit that had originally been attributed to the mystery planet.

To this day, no planet has been found in Vulcan's position. "It is true that a planet could orbit the Sun closer than Mercury and remain stable," says astronomer John Chambers at the Carnegie Institution's Department of Terrestrial Magnetism. "However, it would have to be at least the size of a large asteroid, otherwise the effect of solar radiation on its orbit would cause it either to collide with Mercury or the Sun within the lifetime of the Solar System. I think observations have ruled out the existence of anything this large."

Yet the hunt still continues - not for a planet called Vulcan, but for much smaller bodies named Vulcanoids, thought to exist between Mercury and the Sun. These would appear in the form of asteroids dancing in a band around our star.

A team hunting for such objects includes Andrew Steffi, Dan Durda and Alan Stern (the principal investigator of the New Horizons mission currently on the way to Pluto), who have searched for Vulcanoids using the help of NASA's STEREO Heliospheric Imager satellites. This trio of spacecraft scrutinises solar eruptions spreading into space. However the satellites have yet to find any sign of Vulcanoids. "By measuring how efficient we were at detecting fake objects, we can say that if there were a Vulcanoid larger than six kilometres (3.7 miles) across, there is a 99.7 per cent chance we would have found it," Steffi explains. "There are low odds of being any Vulcanoid larger than this. Our ability to detect objects smaller than that is limited, for the simple reason that smaller objects reflect less sunlight and therefore appear fainter."

Regardless, there is a small chance that Vulcanoids could still be lurking. While Steffi's team trawled through large amounts of data, David Vokrouhlicky, a professor of astrophysics at Charles University's Astronomical Institute in Prague, has taken a more theoretical approach in the hunt for these chunks of rock on the doorstep of our Sun. "There was some nice work done by Vokrouhlicky and his colleagues, showing that any Vulcanoids smaller than about one kilometre (0.6 miles) would get pushed out of their stable orbits by radiation pressure from the Sun," adds Steffi. "So there is this really narrow window where potential Vulcanoids could be big enough to remain on stable orbits for 4.5 billion years, but still be too small for us to detect them."

That's not to say that Steffi hasn't made some guesses of his own about the Vulcanoids. He and his team think that any potential orbits of these chunks of rock would end up crossing, causing them to smash into one another like bumper cars in a fairground ride. "Since they're so close to the Sun, the relative velocities between two Vulcanoids would be roughly 10-20 kilometres (6.2-12.4 miles) per second and a collision would either break them up or, at least, knock off a bunch of fragments. Each fragment would now be on Vulcanoid-crossing orbits and could hit other members, knocking off more bits," Steffi says. This process, called collisional erosion, can whittle down a population of kilometre-sized or larger objects into smaller pieces in a billion years or less. "It's not too dissimilar to what happened in the movie *Gravity*, where a bunch of high-velocity debris on crossing orbits reduces the larger orbits [of satellites] to fragments."

Did a Mars-sized world once smash into young Earth to make our Moon?

If they exist, it's said that the Vulcanoids - a population of asteroids inside the orbit of Mercury - could easily avoid being detected due to their small size

The Vulcanoids would shrink to such a size that their orbits are modified by the Sun's radiation, directing them on a collision course with Mercury or planetary neighbour Venus, or even throwing them into the fiery heat of the Sun where they would evaporate. With no obvious clues for their existence, Steffi is left feeling somewhat sceptical. "I think it's more likely that Vulcanoids simply don't exist today, if they ever existed at all," he says almost resignedly.

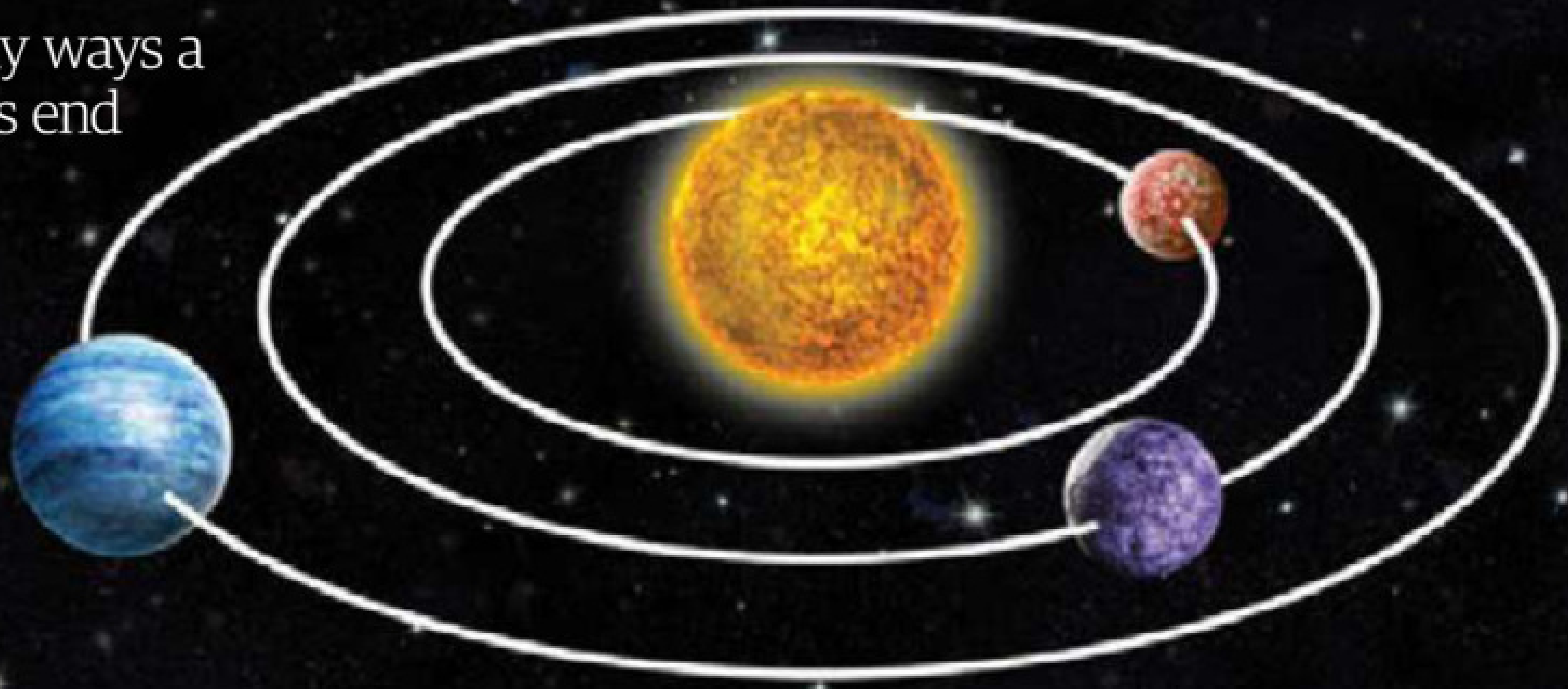
Jack Lissauer, a co-investigator on the exoplanet mission Kepler at NASA's Ames Research Center, is a bit more hopeful. He thinks that the Vulcanoids are very likely to have been part and parcel of the younger Solar System. "Some tiny Vulcanoids that formed from the burnt-out remains of comets may even exist today," he says.

When it comes to speculating about other worlds that could be or could have been knocking around our neighbourhood, Lissauer likes to stay quite open-minded. After all, alongside the SETI Institute's Mark Showalter, he discovered two of Uranus' moons: Mab and Cupid. What's more, he

> "Vulcanoids could be big enough to remain on stable orbits for 4.5 billion years, but still be too small for us to detect them"
>
> **Andrew Steffi, Vulcanoid hunter**

How planets die

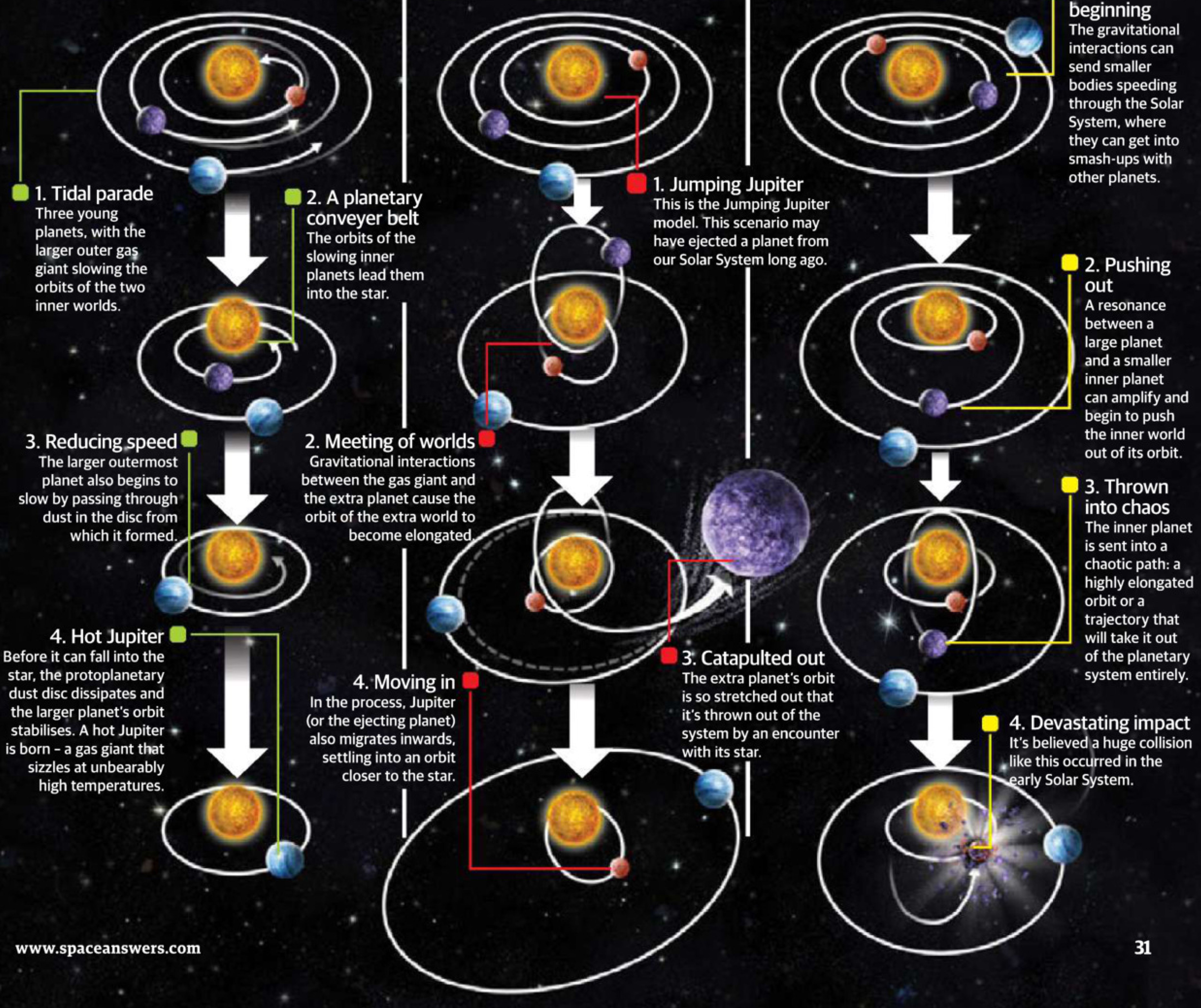
Discover the many ways a world can meet its end



Being eaten alive

Getting kicked out

Collision course



1. Tidal parade
Three young planets, with the larger outer gas giant slowing the orbits of the two inner worlds.

2. A planetary conveyer belt
The orbits of the slowing inner planets lead them into the star.

3. Reducing speed
The larger outermost planet also begins to slow by passing through dust in the disc from which it formed.

4. Hot Jupiter
Before it can fall into the star, the protoplanetary dust disc dissipates and the larger planet's orbit stabilises. A hot Jupiter is born – a gas giant that sizzles at unbearably high temperatures.

1. Jumping Jupiter
This is the Jumping Jupiter model. This scenario may have ejected a planet from our Solar System long ago.

2. Meeting of worlds
Gravitational interactions between the gas giant and the extra planet cause the orbit of the extra world to become elongated.

3. Catapulted out
The extra planet's orbit is so stretched out that it's thrown out of the system by an encounter with its star.

4. Moving in
In the process, Jupiter (or the ejecting planet) also migrates inwards, settling into an orbit closer to the star.

1. In the beginning
The gravitational interactions can send smaller bodies speeding through the Solar System, where they can get into smash-ups with other planets.

2. Pushing out
A resonance between a large planet and a smaller inner planet can amplify and begin to push the inner world out of its orbit.

3. Thrown into chaos
The inner planet is sent into a chaotic path: a highly elongated orbit or a trajectory that will take it out of the planetary system entirely.

4. Devastating impact
It's believed a huge collision like this occurred in the early Solar System.

thinks that a fifth terrestrial world similar to our inner planets could once have orbited between Mars and the Asteroid Belt, created with the other terrestrial planets during the planet-forming era. This additional world, he reasoned, could explain the Late Heavy Bombardment (LHB) when a huge shower of asteroids wreaked havoc during Earth's Hadean period – our planet's first geologic eon.

This was a hellish period in Earth's past, when it was rife with unbearable heat and intense volcanic activity, beginning with its formation some 4.5 billion years ago. "The LHB is an event in the history of the Solar System responsible for most of the craters and impact basins we see today on the Moon, Mars and Mercury," explains Chambers, who is also in favour of the idea of a Planet V. Alongside Lissauer, he came up with the idea of this extra planet. "The mystery of the LHB is that it happened about half a billion years after the planets finished forming, so something must have changed in the Solar System at that time in order to cause all those impacts."

Both Chambers and Lissauer warn that the idea of a Planet V is highly speculative and for now remains unproven. However, Chambers relates a story to **All About Space** that chronicles this past world's possible life in our Solar System. "An extra planet located between Mars and the Asteroid Belt could remain there for hundreds of millions of years before its orbit became unstable and it either fell into the Sun or was thrown out by Jupiter's gravity," he says. "For the final portion of its lifetime, this extra planet would have had an orbit crossing the Asteroid Belt and its gravity may have nudged many asteroids out of the belt onto orbits. Here they eventually collided with the Moon or one of the planets, creating the LHB."

The large number of craters that pepper the rocky worlds of our Solar System are still being probed by astronomers across the entire scientific community. Another idea for the so-called LHB brought forward by an independent group of researchers who met at Nice Observatory, in France, is aptly named the Nice model. In this scenario the orbits of the younger outer planets altered slowly over time as the gravity of the gas giants steadily removed many asteroids from the Kuiper Belt out beyond the orbit of Neptune. "Shortly before the time of the LHB, the orbits of Jupiter and Saturn entered a temporarily unstable configuration called a resonance. Probably Jupiter was orbiting the Sun exactly three times for every two orbits of Saturn," says Chambers of the Nice model. "For a few million years the orbits of Jupiter, Saturn, Uranus and Neptune changed dramatically and their gravity flung asteroids out of both the Asteroid and Kuiper Belts, some of which hit the Moon and inner planets."

Of course, at present, we're not fully sure of which theory – the Nice model or that of Chambers and Lissauer – is correct. While it hasn't escaped the notice of Chambers that both could be wrong, he states that many researchers seem to favour the Nice model. Either way, there seems to be a general consensus that chunks of space rock have somehow been thrown wildly across the Solar System, crashing into anything and everything in their path – leaving their legacy for astronomers to find.

Fortunately for Chambers and Lissauer, academics like Alessandro Morbidelli (among those who

The invisible Solar System

What would our Solar System look like if the hidden worlds – past and present – revealed themselves?

Planet V
Distance from Sun: 1.85AU
Mass: 0.25 Mars masses
Type: Rocky planet
Status: Ejected

Mars
Distance from Sun: 1.5AU
Mass: 0.11 Earth masses
Type: Rocky planet
Status: Outermost terrestrial planet

Ceres
Distance from Sun: 2.77AU
Mass: 0.00015 Earth masses
Type: Rocky body
Status: Dwarf planet in Asteroid Belt

Venus
Distance from Sun: 0.7AU
Mass: 0.82 Earth masses
Type: Rocky planet
Status: Closest planet to Earth

Earth
Distance from Sun: 1AU
Mass: 5.9 trillion trillion kg
Type: Rocky planet
Status: Only planet that we know of with life and liquid water

Mercury
Distance from Sun: 0.39AU
Mass: 0.055 Earth masses
Type: Rocky planet
Status: Closest planet to Sun

Theia
Distance from Sun: 1AU
Mass: Similar to Mars
Type: Rocky protoplanet
Status: Destroyed in creation of Earth's Moon

Vulcanoids
Distance from Sun: 0.06-0.21AU
Type: Asteroid Belt
Status: Unconfirmed

Makemake

Distance from Sun: 45.8AU
Mass: Unknown
Type: Dwarf planet
Status: Icy body in Kuiper Belt

Haumea

Distance from Sun: 43AU
Mass: 0.00066 Earth masses
Type: Dwarf planet
Status: Icy body in Kuiper Belt

Suspected super Earth or ice giant

Distance from Sun: 100s of AU
Mass: Up to 10 Earth masses
Type: Unknown
Status: Undetected

Jupiter

Distance from Sun: 5.2AU
Mass: 317.8 Earth masses
Type: Gas giant
Status: Largest planet in Solar System

Saturn

Distance from Sun: 9.6AU
Mass: 95.2 Earth masses
Type: Gas giant
Status: Sixth planet from the Sun

Eris

Distance from Sun: 68AU
Mass: 0.0028 Earth masses
Type: Dwarf planet
Status: Icy trans-Neptunian object

Pluto

Distance from Sun: 39AU
Mass: 0.00218 Earth masses
Type: Dwarf planet
Status: Former planet

Uranus

Distance from Sun: 19.2AU
Mass: 14.5 Earth masses
Type: Ice giant
Status: Tipped onto its side following suspected collision

2012 VP113

Distance from Sun: 80-100s of AU
Mass: Unknown
Type: Dwarf planet
Status: Icy trans-Neptunian object

Neptune

Distance from Sun: 30AU
Mass: 17 Earth masses
Type: Ice giant
Status: Last known planet in Solar System

Third ice giant

Distance from Sun: Approximately 15AU
Mass: Around Uranus' mass
Type: Ice giant
Status: Ejected

Tyche/Planet X

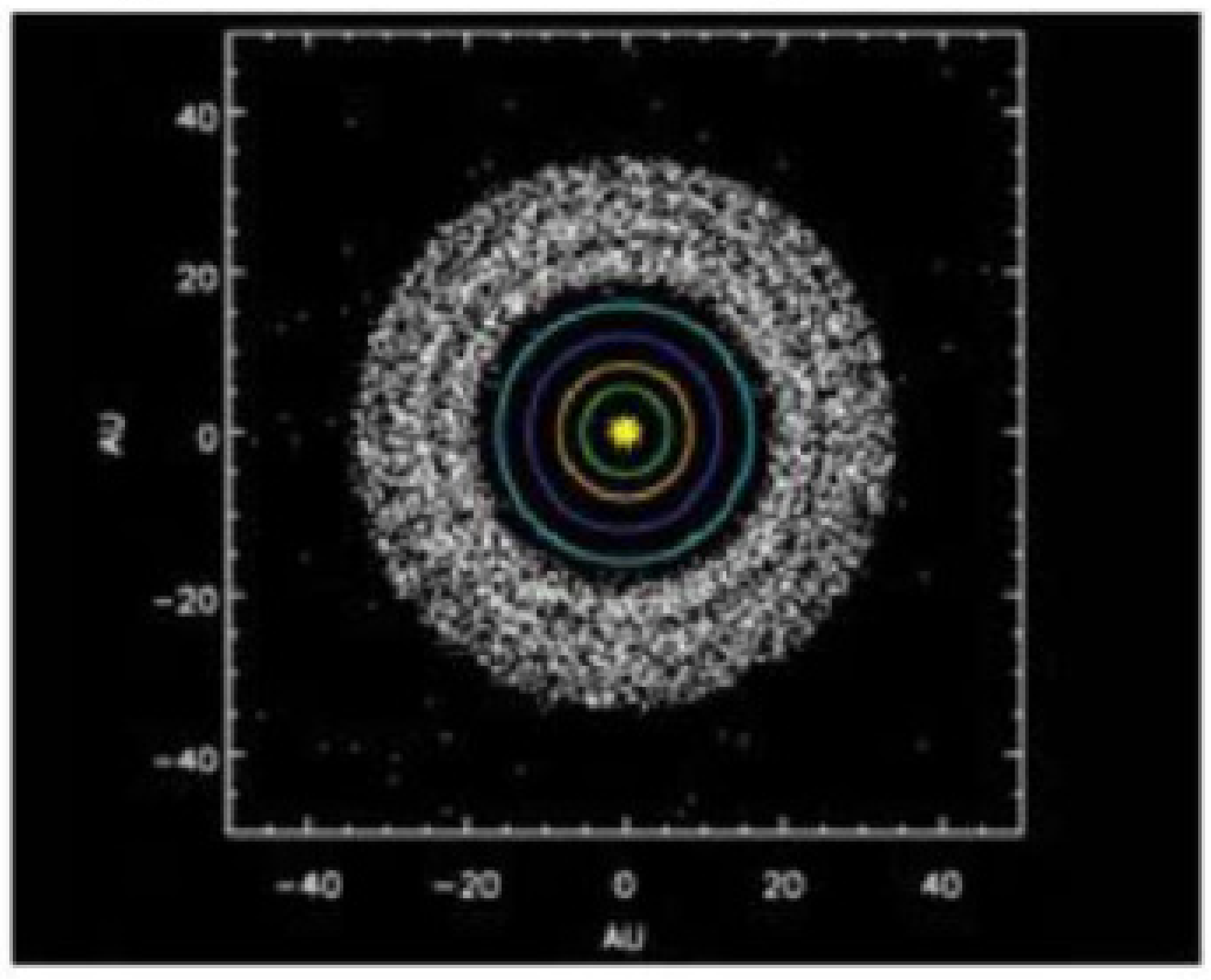
Distance from Sun: 15,000AU
Mass: Up to 2 Jupiter masses
Type: Gas giant
Status: Undetected

Nemesis

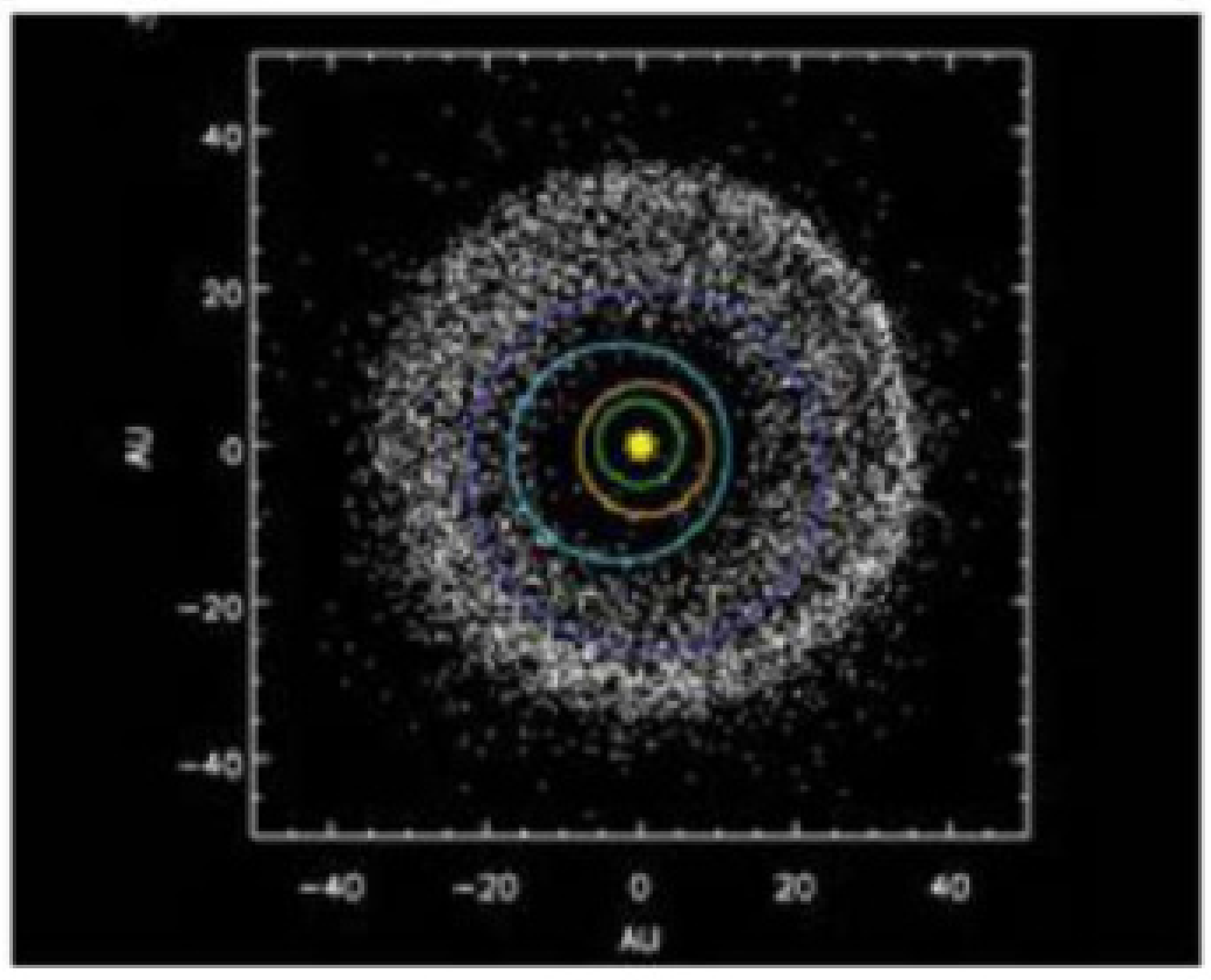
Distance from Sun: 95,000AU
Mass: 0.0075-0.5 times mass of Sun
Type: Brown dwarf or red dwarf
Status: Undetected

The Nice model

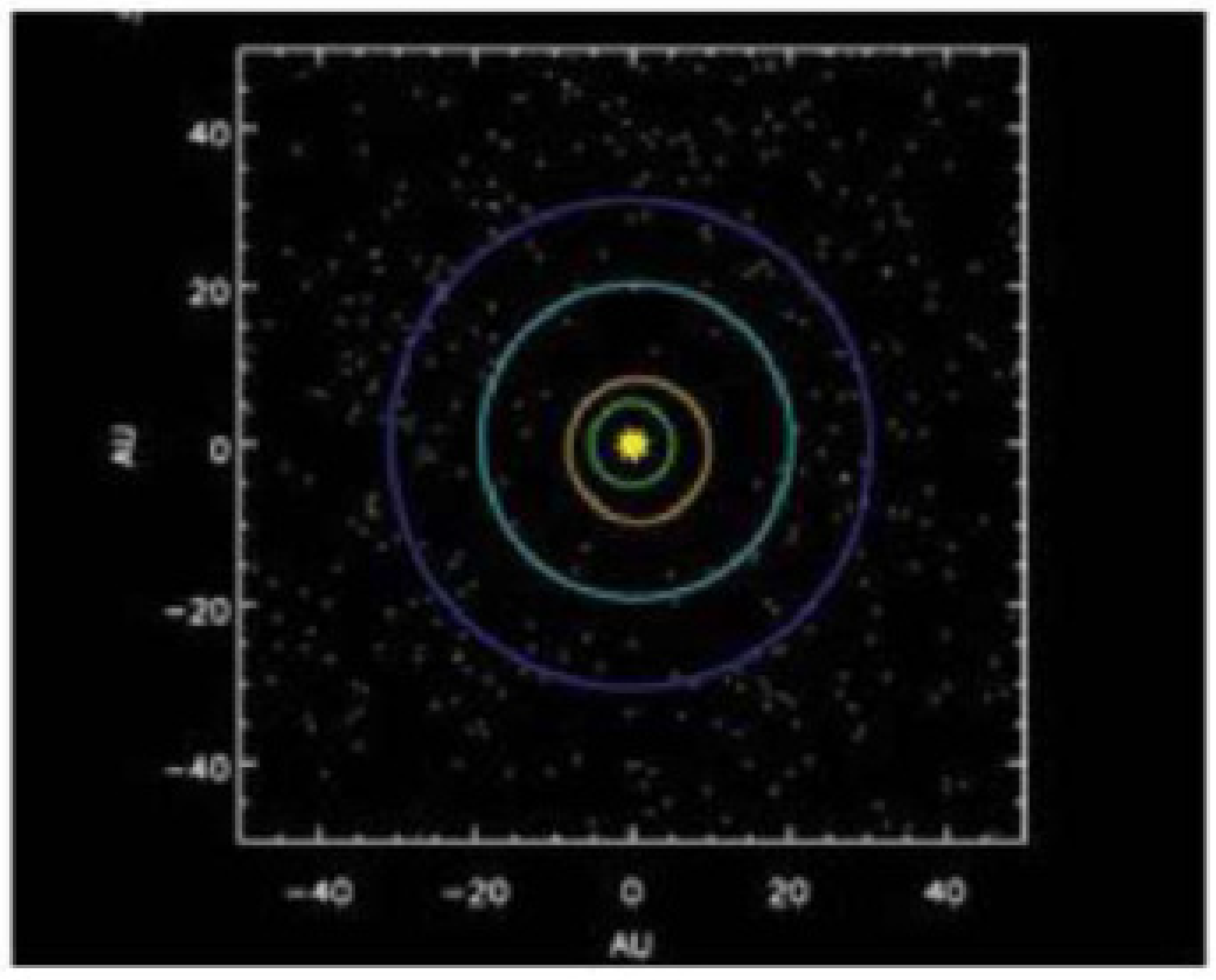
Named after the city where it was initially developed, the Nice model describes what we understand to be the dynamic evolution of our Solar System. The theory states that the giant planets broke free from an initially compact configuration into their current positions.



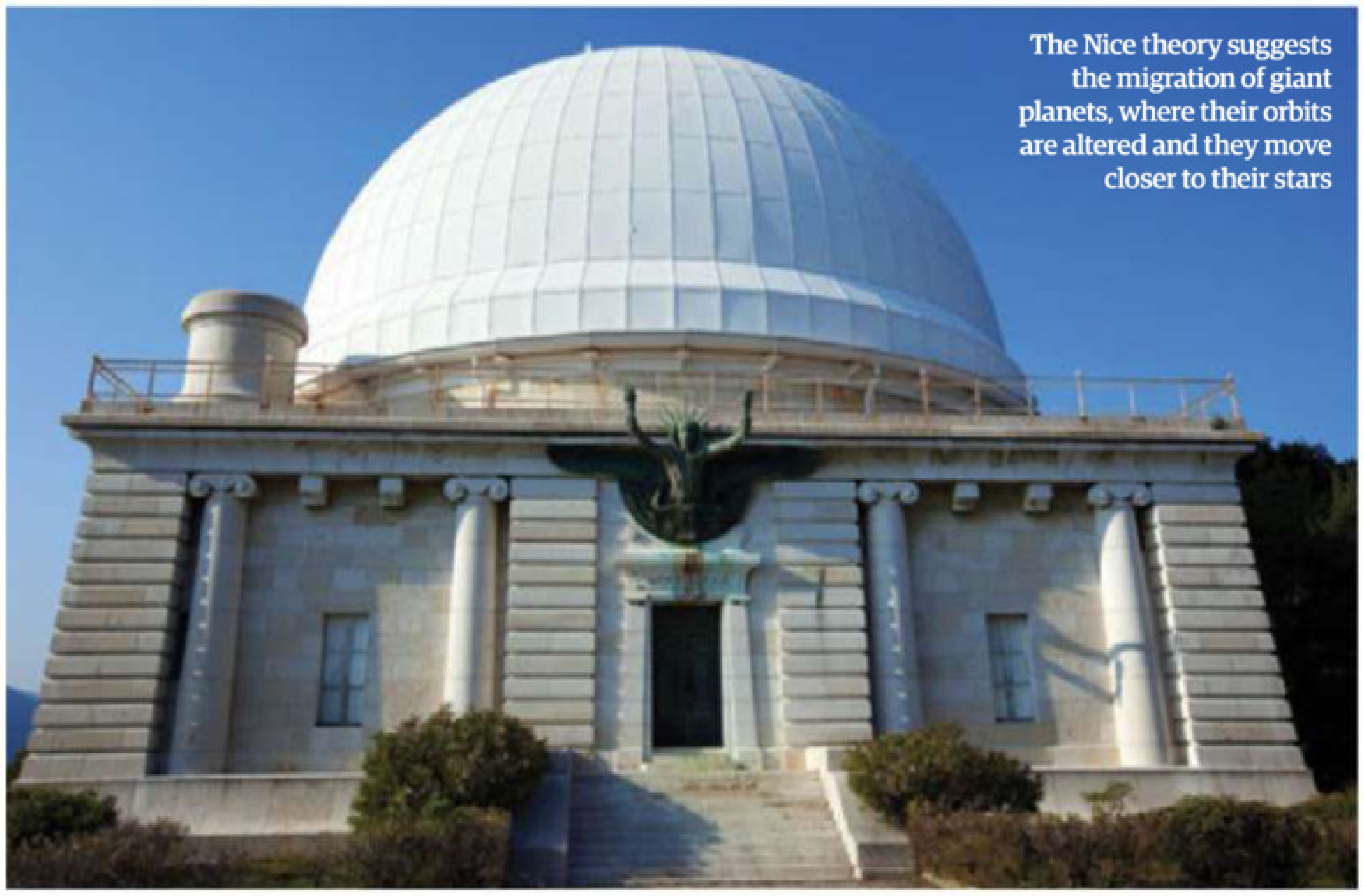
Young planetary orbits
After the dissipation of the gas and dust of the Solar System's primordial disc, Jupiter, Saturn, Uranus and Neptune could be found on a nearly circular orbit somewhere between 5.5 and 17AU.



Causing complete chaos
After a slow migration, Jupiter and Saturn cause a regular and periodic gravitational influence on each other, causing eccentric orbits, which destabilises the Solar System entirely.



A shower of planetesimals
Neptune and Uranus hit the planetesimal, scattering rocks from their orbits to the outer reaches, removing nearly all the primordial disc's mass that batters the inner planets.



The Nice theory suggests the migration of giant planets, where their orbits are altered and they move closer to their stars

> "After Earth formed, a protoplanet called Theia smashed into our planet, ripping off a large chunk of our world's mantle"

originally suggested the Nice model) and Ramon Brasser have been giving Planet V's existence some careful thought. The duo calculated that for Planet V to create the force of the LHB it would need to have cast out a good 95 per cent of the Asteroid Belt during this era in the Solar System – or a whopping 98 per cent of the inner portion of this same belt.

Running computer simulation after computer simulation, the astronomers could see that Planet V would have been ejected some 400 million years after the formation of the Solar System and would have had a mass of around a quarter of Mars. "I think they are basically right," Chambers admits. "It's almost certainly true that the Asteroid Belt once contained much more mass than it does today."

Looking around our Solar System, you'll find that the current total mass of asteroids is tiny, at around two-thousandths that of Earth's. "Models for the formation of the Solar System all agree there was a lot more stuff there when the planets began forming," Chambers says. "There are numerous ideas for how the Asteroid Belt lost most of its original material – mostly these ideas involve Jupiter throwing its weight around in one way or another, so that its gravity removed objects from the Asteroid Belt." In the light of these theoretical models, the idea that the Asteroid Belt lost a lot of material due to the existence of a so-called Planet V isn't a huge stretch of the imagination.

There is a variation on the Planet V hypothesis, which proposes that it was another ice giant, such as Neptune, nestled quite comfortably between ringed planets Saturn and Uranus. "This planet could have orbited between Saturn and Uranus, while Neptune could have orbited closer to the Sun than Uranus prior to the LHB," speculates Lissauer. This fifth giant planet is likely to have been thrown to its doom by being catapulted out of the Solar System following a gravitational encounter with neighbouring Saturn and Jupiter, in the so-called Jumping Jupiter scenario. Here Jupiter jumps due to gravitational interactions with Uranus or Neptune, before throwing out another planet (a fifth world) that's been left out in the cold.

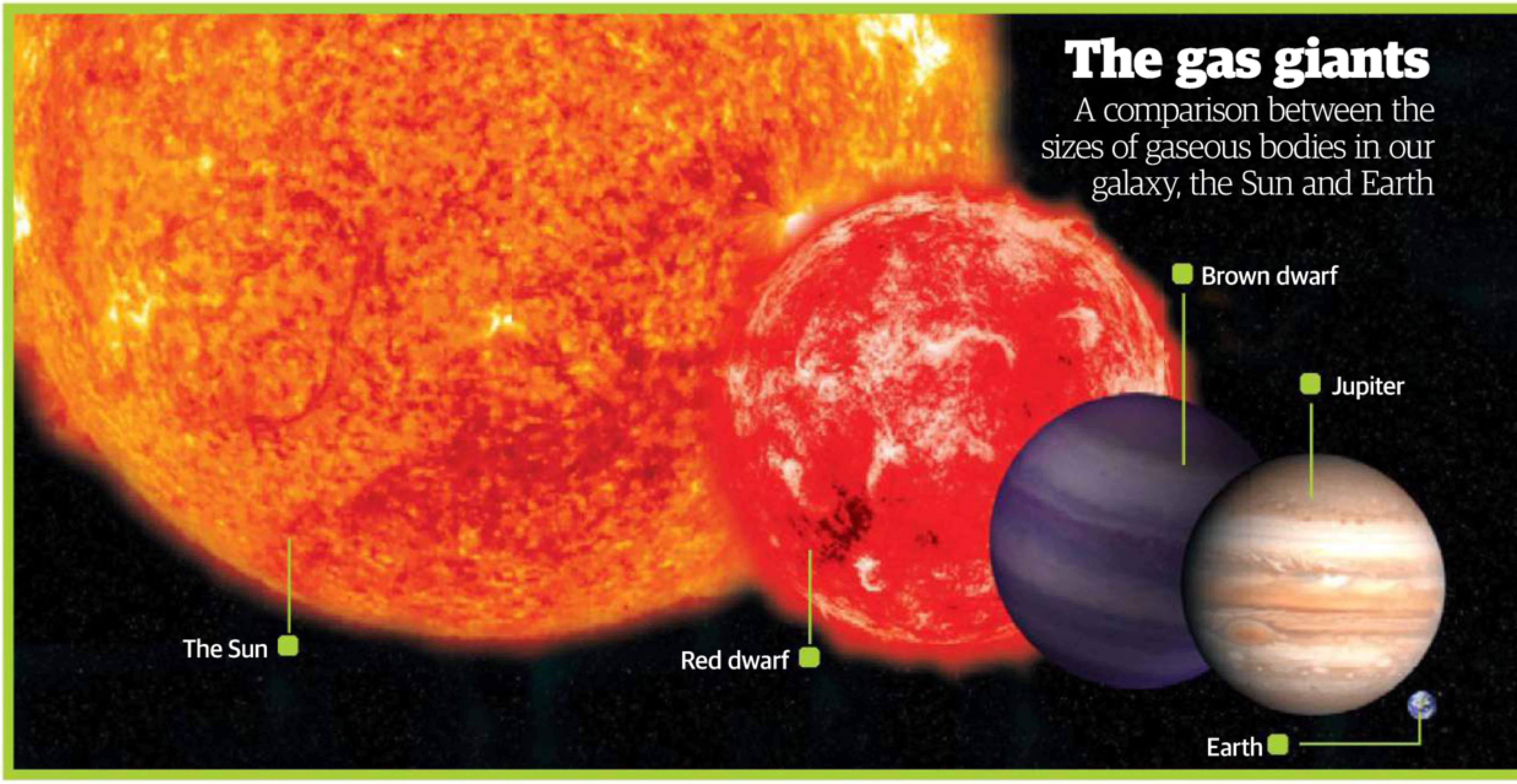
The Southwest Research Institute's David Nesvorny thinks that the jumbling of planets could have scattered many small bodies, pushing some inwards and others outwards, with some ending up in the Kuiper Belt. Others are likely to have smashed into the terrestrial planets and the Moon. "Researchers have simulated the orbital evolution of hypothetical objects between the orbits of the outer planets using computers. In most cases these orbits are so unstable that the objects are removed in less than a billion years," says Chambers. "I believe one study found a slim chance that something could survive between Saturn and Uranus for the age of the Solar System, but it would have to be no more than a few hundred kilometres in diameter, otherwise it would have been seen by now."

The impacts of comets during the LHB are separate events to one of the biggest collisions of all that's thought to have created our Moon. Scientists believe that shortly after Earth formed, a protoplanet called Theia smashed into our planet, ripping off a large chunk of our world's mantle, which went into forming the Moon. Theia, which was around the size of Mars, was totally destroyed. The early Solar System was swarming with bodies like Theia, some of which crashed into planets like this young world did, while others were ejected into the Oort Cloud or beyond.

While an extra planet may hold the answer to the LHB, comets continue to periodically impact the

The gas giants

A comparison between the sizes of gaseous bodies in our galaxy, the Sun and Earth



inner planets. One astronomer in particular thought there was an unusual regularity to this deadly influx of space snowballs, revealed in the period between mass extinctions on Earth, when it was implied these collisions wiped out many species on our planet. In 1984 American professor of physics Richard Muller suggested that a companion to the Sun - either a brown or red dwarf called Nemesis - lurked beyond the comet-packed Oort Cloud at a distance of around 1.5 light years. This body perturbed the comets in the Oort Cloud as it orbited every 26 million years, causing a wave of comets to come crashing through the Solar System. Looking back at geological records, Muller believed that Nemesis would explain a cycle of mass extinctions, snuffing out swathes of life on our planet, which seems to occur at regular intervals - roughly every 26 million years.

Several research teams agree there is no denying the pattern here. However, just what form Nemesis takes isn't agreed by all parties. David Whitmire and Albert Jackson believe that Nemesis is a failed star - a brown dwarf that stalks the outer edges of the Solar System. Muller, on the other hand, argues that this object is likely to be a red dwarf star, glowing at an apparent magnitude of somewhere between 7 and 12 from our position on Earth. "Red dwarfs are far more common," Muller explains. "I suspect [Whitmire and Jackson] mistakenly believed that a red dwarf would have been seen and so were forced to assume a far fainter brown dwarf."

Either way, Nemesis would shine brightly in infrared light. WISE - NASA's Wide-field Infrared Survey Explorer - carefully scanned the sky searching for, among other things, a companion star to the Sun, but the mission's reels of data have turned up nothing. Scientists have now ruled out any

The Nice Observatory's 76cm (30in) refractor, when built, boasted the title of the world's largest and longest telescope

Jupiter-sized planets out to 26,000 times the distance of Earth from the Sun and any Saturn-sized bodies out to 10,000 times that distance in the Oort Cloud. Even Muller accepts it isn't looking good for the hypothetical stellar companion. "Maybe it isn't there," he says. "I think the WISE measurements were pretty thorough... Calculations show that Nemesis must be orbiting in the plane of the galaxy, otherwise its orbit would be unstable. I don't know if WISE was able to do a thorough job in the plane of the galaxy, so it could be hiding there."

The results from WISE also pose similar problems for a theory suggested by a group led by John Matese, who proposed the presence of a gas giant in the Oort Cloud to explain the similarities between the points of origin of long-period comets. They called this unseen planet Tyche, but you might have heard it being referred to as 'Planet X'.

"WISE's observations have indeed ruled out the possibility of a planet at the large mass end of the range that we suggested was possible," explains Matese, claiming there is a loophole that could still allow Tyche to exist. "It's not clear that WISE can rule out the existence of a planet at the low mass end, around one or two times the mass of Jupiter, at the distances suggested. I admit that most of the possible scenarios that we allowed for have been precluded."

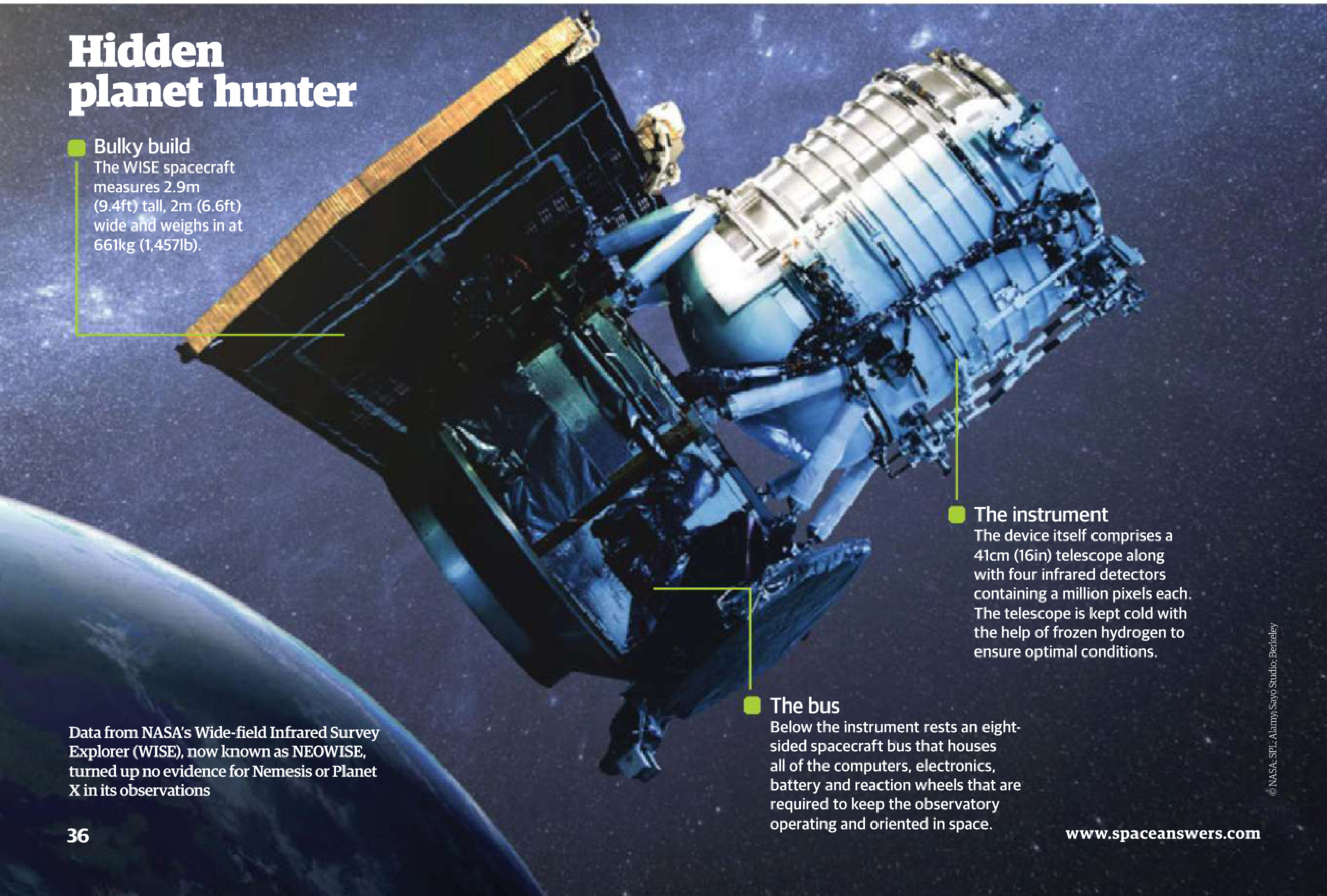
So, both Muller and Matese hold out only slim hope for their respective unseen objects, but if Nemesis and Tyche don't exist, it doesn't mean that the Oort Cloud and Kuiper Belt are empty of large objects. Four dwarf planets – Pluto, Eris, Makemake and Haumea – are known to exist out there and now a fifth dwarf in the outer Solar System has been found, currently referred to as 2012 VP113.

This new world, found by the Dark Energy Camera (DECam) on the NOAO four-metre (13-foot) telescope in Chile, is the most distant object uncovered so far, reaching hundreds of times farther from the Sun than Earth. According to its discoverers, Scott Sheppard of Carnegie Institution and Chad Trujillo of Gemini Observatory, the similarity of its orbit to other distant world residents of the Kuiper Belt and inner Oort Cloud suggest that something is pushing these bodies into these orbits. That something could be a lost world up to ten times the mass of Earth – another hidden planet for scientists to unmask.

Many astronomers predict that dozens or even hundreds of planets could be found in the Oort Cloud. Some may be ejected there by interactions with other bodies, while others may have been flung so far out, having wandered so many light years in distance, that they've been captured by another star as an exoplanet. With high-tech observatories scanning inside and outside our Solar System, it might only be a matter of time before what was once a hidden planet reveals itself as an additional member of our Solar System. ■

Richard Muller suggested that our Sun has a companion red dwarf star called Nemesis which has caused mass extinctions on our planet every 26 million years

Hidden planet hunter



Bulky build
The WISE spacecraft measures 2.9m (9.4ft) tall, 2m (6.6ft) wide and weighs in at 661kg (1,457lb).

The instrument
The device itself comprises a 41cm (16in) telescope along with four infrared detectors containing a million pixels each. The telescope is kept cold with the help of frozen hydrogen to ensure optimal conditions.

The bus
Below the instrument rests an eight-sided spacecraft bus that houses all of the computers, electronics, battery and reaction wheels that are required to keep the observatory operating and oriented in space.

Data from NASA's Wide-field Infrared Survey Explorer (WISE), now known as NEOWISE, turned up no evidence for Nemesis or Planet X in its observations

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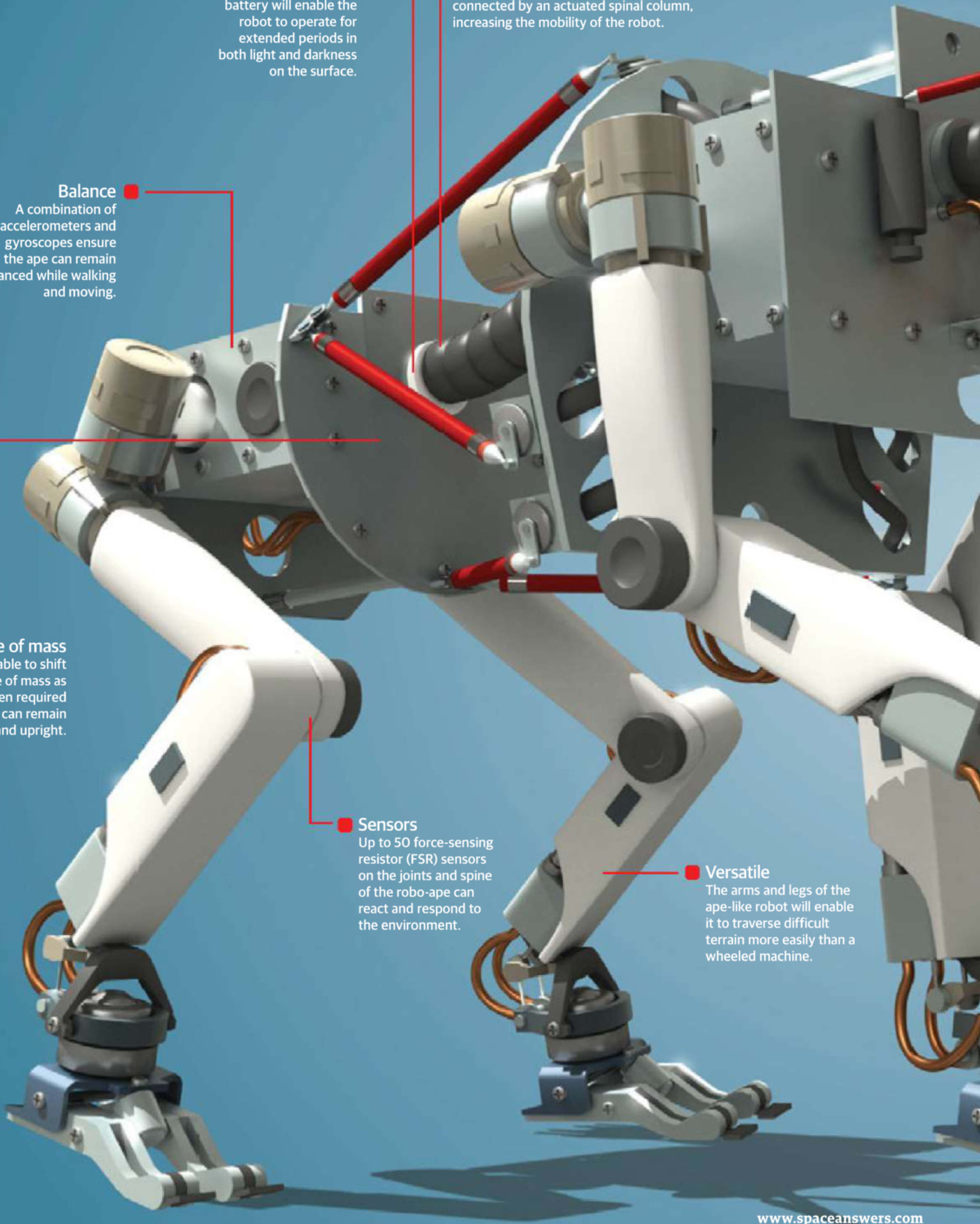
All About Space



Power
A self-contained battery will enable the robot to operate for extended periods in both light and darkness on the surface.

Spine
The front and rear of the ape will be connected by an actuated spinal column, increasing the mobility of the robot.

Balance
A combination of accelerometers and gyroscopes ensure the ape can remain balanced while walking and moving.

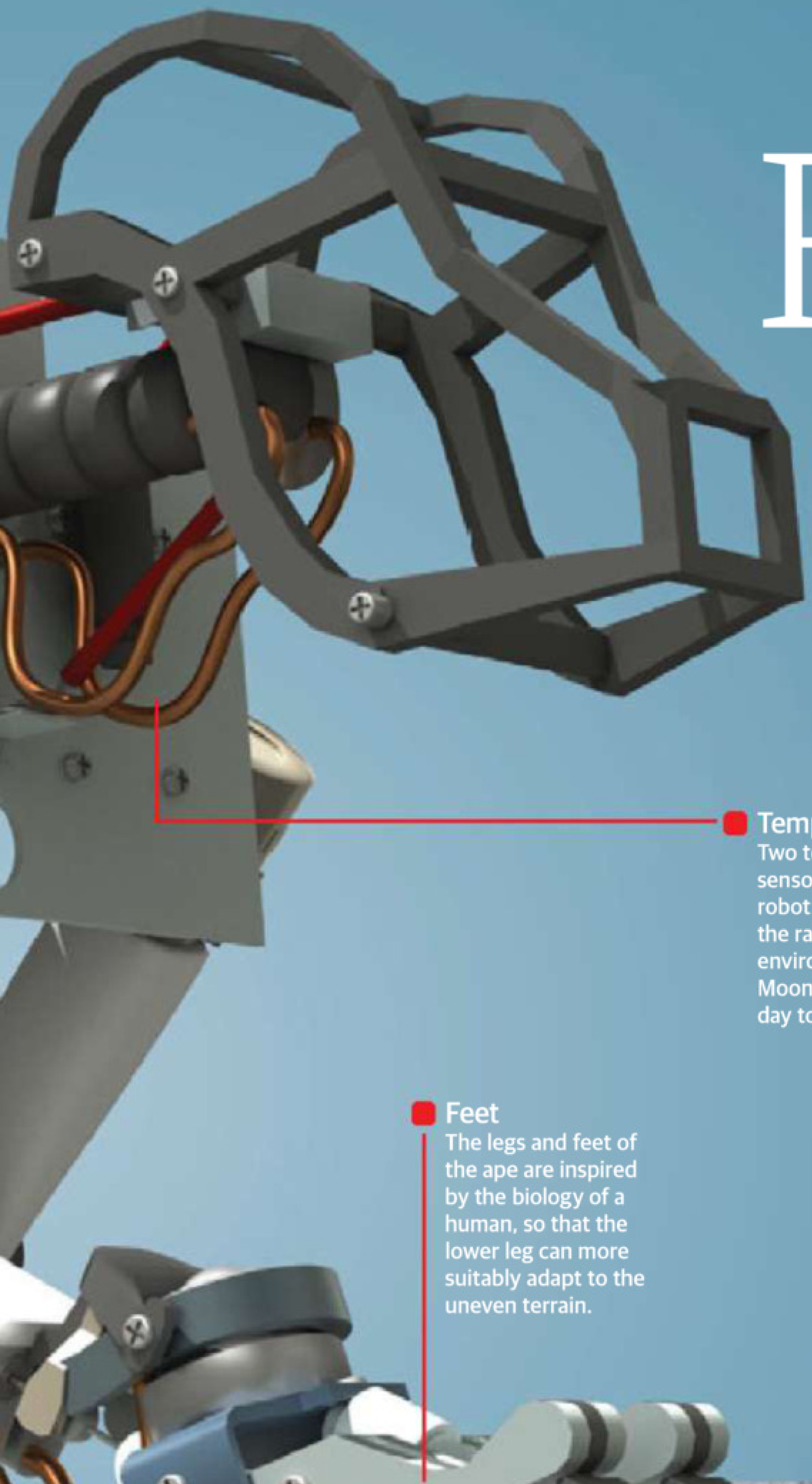
Centre of mass
The ape is able to shift its centre of mass as and when required so that it can remain stable and upright.

Sensors
Up to 50 force-sensing resistor (FSR) sensors on the joints and spine of the robo-ape can react and respond to the environment.

Versatile
The arms and legs of the ape-like robot will enable it to traverse difficult terrain more easily than a wheeled machine.

Robot ape

Introducing the iStruct Demonstrator, the robo-ape that could one day be clambering across the Moon



Temperature
Two temperature sensors enable the robot to deal with the radically changing environment on the Moon as it alters from day to night.

Feet
The legs and feet of the ape are inspired by the biology of a human, so that the lower leg can more suitably adapt to the uneven terrain.

The German Research Centre for Artificial Intelligence (DFKI) and the University of Bremen have put together a prototype four-legged robo-ape, known as the iStruct Demonstrator – a machine that will employ several smart innovations to help it traverse the Moon's hills and craters. The benefits of such a proposal largely centre around its manoeuvrability – where a rover may struggle with the slope of a crater or rocks strewn across the ground, a robo-ape could clamber up a slope on all-fours or carefully pick its way over rocks.

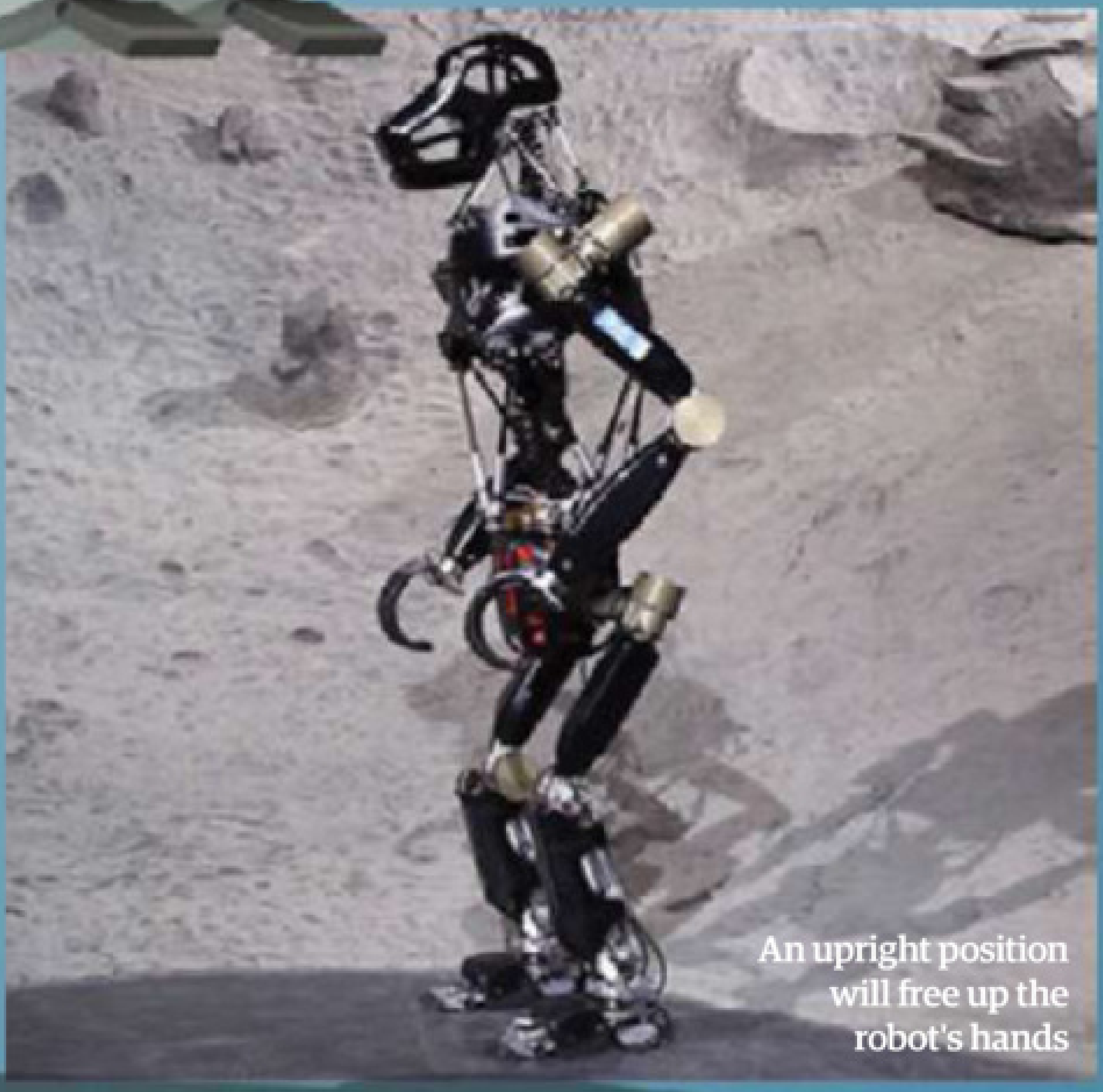
Weighing in at 18 kilograms (40 pounds) and with dimensions of 66 x 43 x 75 centimetres (26 x 17 x 30 inches), the robot is similar in both size and stature to real apes, which are well known for their versatility in many environments. Another benefit of the design is that the robot could stand on its hind legs while its hands are used for other purposes.

There are 43 sensors that can detect the force pressed on them when the machine walks, enabling it to remain stable. Six sensors on the exposed sections of the ape are used for collision-detection, distance sensors tell it how far away the ground is as it walks, while a three-axis accelerometer orientates the feet so that steps are taken according to the slope of the ground below.

The University of Bremen and DFKI partnership has also incorporated something called a multi-locomotion system. This replaces an otherwise solid and inflexible connection between either end of the iStruct Demonstrator's body with an actuated spinal column. From this flexible core, a six-axis force/torque sensor makes sure the ape doesn't topple over while walking, or performing more-complicated actions when moving around on all four limbs.

Gone would be the slow progress made by a rover, analysing the ground ahead before trundling on. Instead, robo-apes could adeptly pick their way across treacherous terrain to perform key science in alien locales.

While the iStruct Demonstrator is just a prototype for future innovative robot explorers, it's possible that a descendant of this robo-ape could one day visit the Moon or even worlds further afield. Places that could prove too dangerous or simply too expensive for a manned mission could be probed by this relatively cheap piece of technology. With continuing iterations and improvements, descendants of the iStruct could remain on the far side of the Moon. A trip to Mars could even be on the cards, with the robot reacting to its environment and paving the way for a manned mission.



An upright position will free up the robot's hands

© Adrian Mann; DFKI

DEADLY SPACE JUNK

Hurtling around the Earth at thousands of kilometres per hour, out-of-control space debris can have a devastating effect on anything that crosses its path

Written by Giles Sparrow

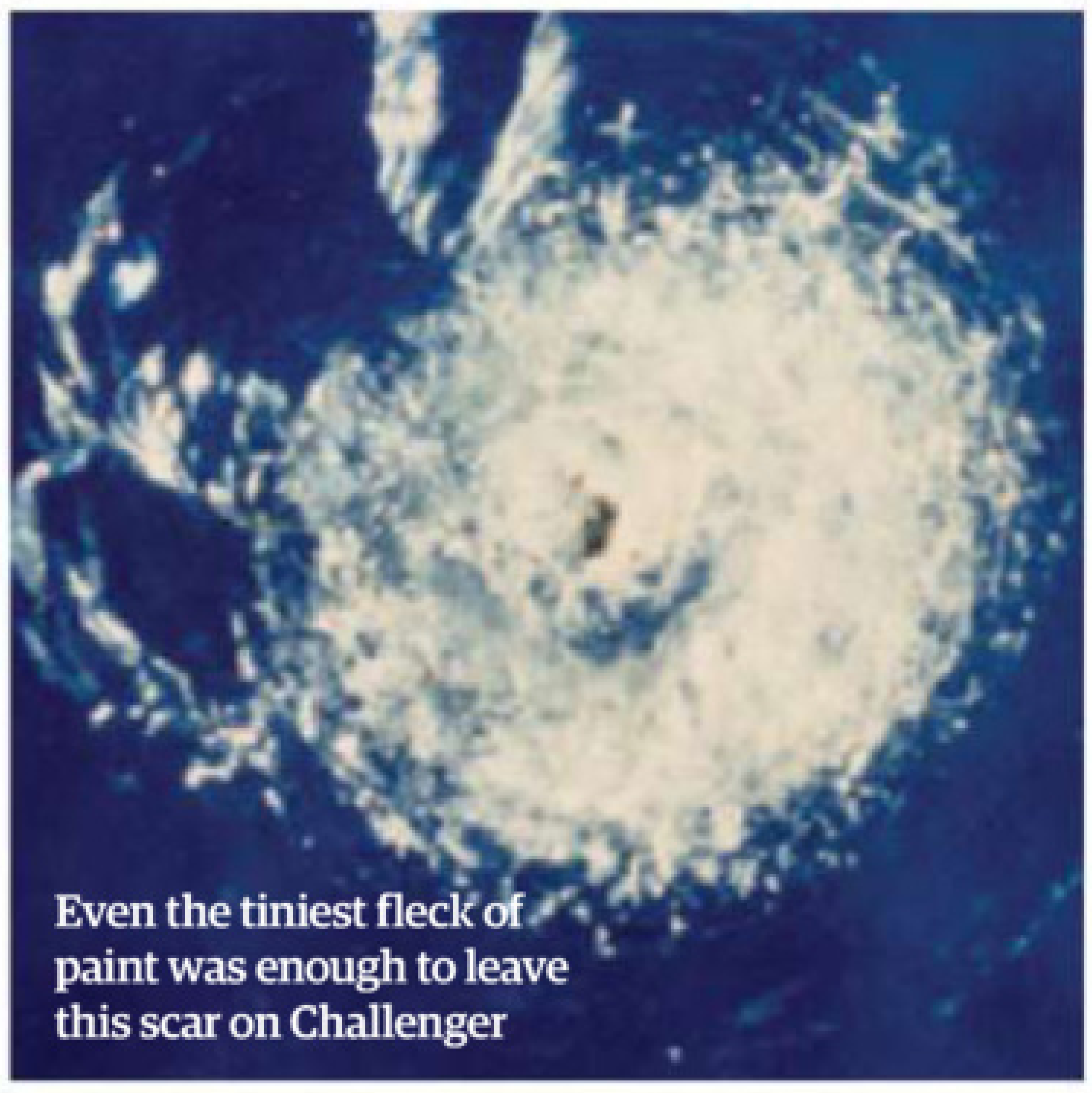
It's perhaps the most electrifying sequence in the awe-inspiring blockbuster film *Gravity* - the moment a blizzard of incoming space debris travelling at terrifying speed lays waste to everything in its path, destroying both the International Space Station and an orbiting Space Shuttle, leaving two spacewalking astronauts adrift and fighting for their lives.

Fortunately, though, it's the kind of thing that could only happen in a movie... or is it? While the debris storm in *Gravity* is created by a foolhardy missile test on a defunct satellite, space scientists today are increasingly concerned that something very similar could happen by accident, with a runaway cascade of collisions leaving large areas of near-Earth space dangerously inaccessible. If that happens, the effects wouldn't just be felt by a few orbiting astronauts - we could all suffer the substantial consequences.

Ever since the launch of the first satellite, Sputnik 1, back in 1957, humankind has been steadily filling up the space around Earth. Official figures put the number of satellites sent into orbit since the dawn of the Space Age at nearly 7,000 and there are probably a few unacknowledged ones lurking around from the secretive days of the Cold War.

While many of these objects have since re-entered Earth's atmosphere and burnt up - thanks to either

The Jules Verne Automated Transfer Vehicle burnt up harmlessly over the Pacific Ocean



Even the tiniest fleck of paint was enough to leave this scar on Challenger

unstable initial orbits or the slight but inexorable drag of sparse gas in the upper atmosphere – an estimated 2,000 are still circling Earth today.

Given the sheer volume of space available around Earth, that might not seem like a large number, but there's a catch – satellites tend to cluster together in a much smaller number of particularly useful orbits. Low Earth Orbit (LEO), for example, is the zone just a couple of hundred kilometres above the surface that's most easily reached by manned spaceflight and also most useful for many Earth-observing satellites.

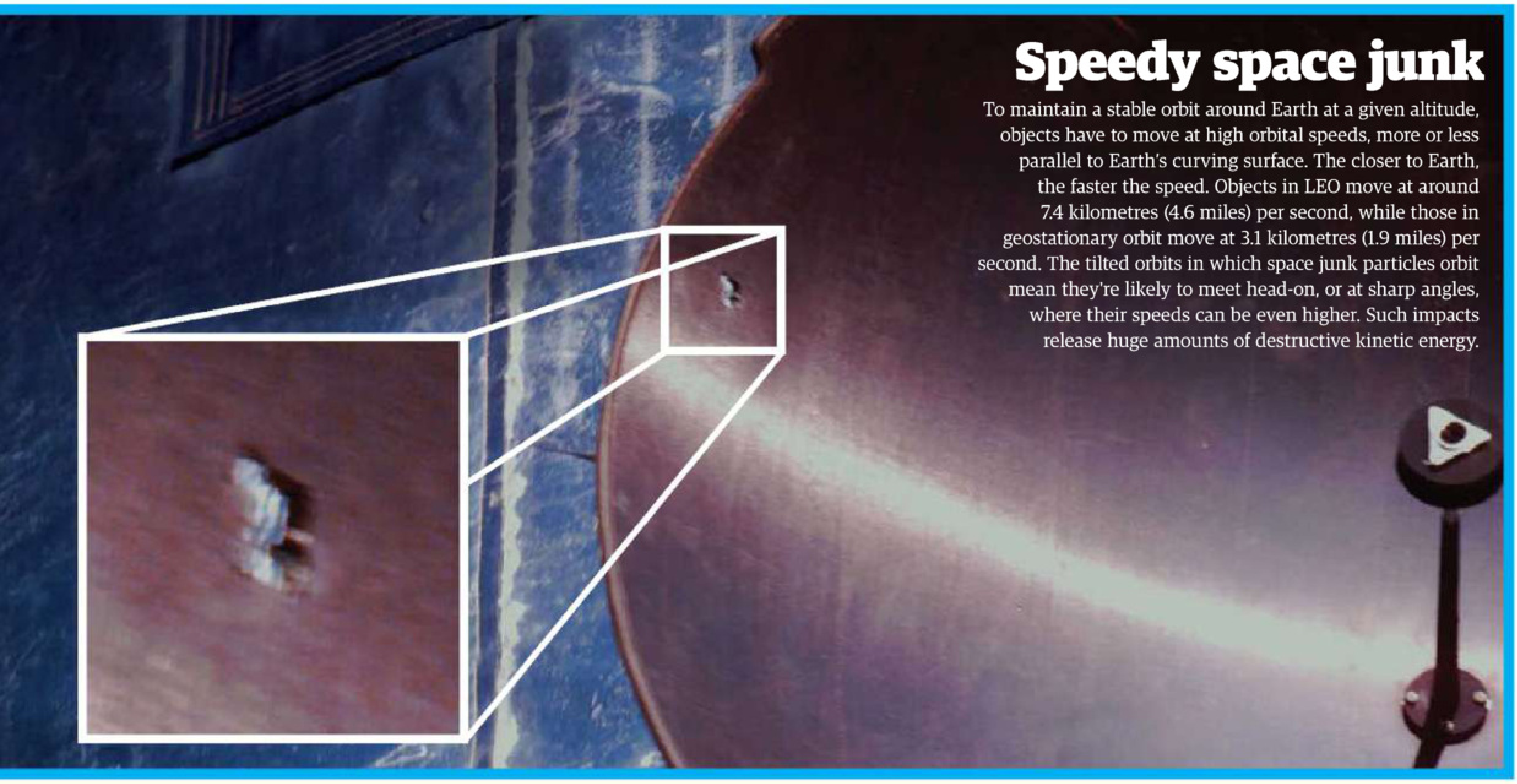
Geostationary orbit, meanwhile, is a very specific circular orbit 35,786 kilometres (22,236 miles) above the equator, in which satellites orbit the Earth in the same period as the planet itself rotates (23 hours, 56 minutes), therefore maintaining a fixed position in the sky as seen from Earth. The majority of weather satellites use this orbit, as well as telecommunications satellites that form such an essential part of the modern global infrastructure.

What's more, launching anything into orbit is a messy business, so even if the lower stages of a rocket simply arc into space before plunging back to Earth, there's every chance they could leave more behind than their intended payloads. Explosive bolts fired to separate launch vehicle components and the ignition of further stages may shake loose chips of paint and even larger fragments of rocket casings, flinging them into their own unpredictable orbits around Earth. Another major problem is that spent rocket casings, languishing idly in orbit, can suffer from spontaneous yet hazardous explosions.

Both NASA and the European Space Agency have programmes dedicated to tracking orbital debris – NASA's Ground-based Electro-Optical Deep Space Surveillance (GEODSS) project searches for material using an array of computerised optical telescopes and super-sensitive television cameras. The technology can only track objects of roughly ten centimetres (four inches) in diameter (with a mass typically around a kilogram, or 2.2 pounds), but GEODSS has so far identified 22,000 different objects in this class. Based on this figure, statistics suggest there could be as many as 500,000 objects in the one to ten-centimetre (0.4 to four-inch) range, plus tens of millions of smaller particles. Other surveys aim to use ground-based radar to track objects too small to be seen by optical telescopes. Maps produced using this data show our planet already surrounded by an alarming halo of debris.

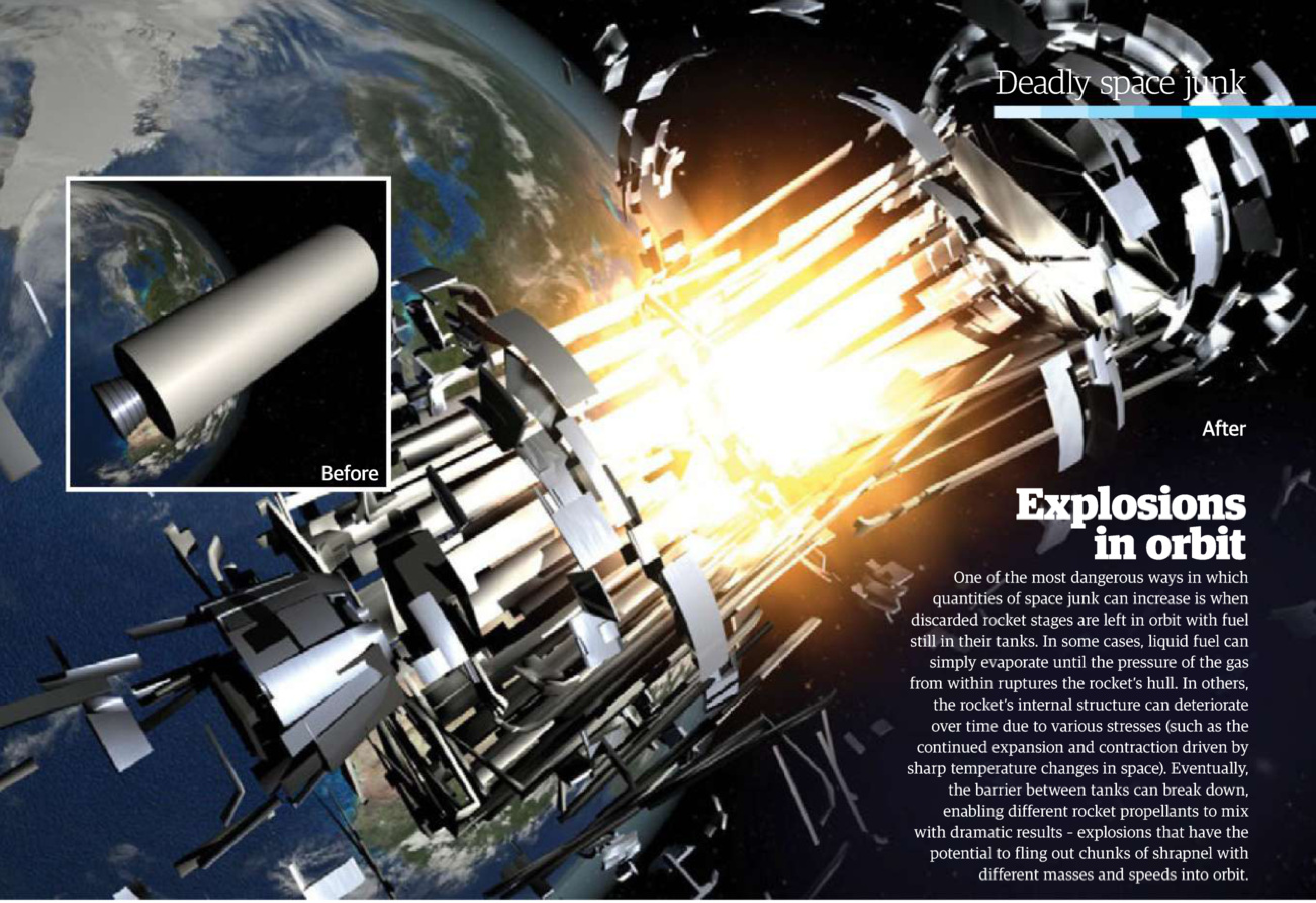
Perhaps it's little wonder, then, that collisions happen. Space scientists received an alarming wake-up call to the growing threat in 1983 when the Space Shuttle Challenger returned to Earth with a substantial crater in one of its reinforced windows. Careful study of the damage back on Earth determined that it was caused by an insubstantial fleck of paint, colliding with the shuttle at several kilometres per second – it's the hypervelocity speed of encounters in orbit that enables even lightweight objects to pack such an unexpected punch.

What's worse, the fairly frequent shuttle flights up to the end of the last decade gave engineers a chance to make regular assessments of the likelihood of impacts in LEO and provided clear evidence that the problem was getting worse – particularly since the late-1990s. In 2006, Atlantis was struck by a tiny object that bored a hole straight through one of the radiator panels on the cargo bay door, while in 2007 Endeavour came home sporting a hole several centimetres across in the same area, that triggered more than a slight cause for concern.



Speedy space junk

To maintain a stable orbit around Earth at a given altitude, objects have to move at high orbital speeds, more or less parallel to Earth's curving surface. The closer to Earth, the faster the speed. Objects in LEO move at around 7.4 kilometres (4.6 miles) per second, while those in geostationary orbit move at 3.1 kilometres (1.9 miles) per second. The tilted orbits in which space junk particles orbit mean they're likely to meet head-on, or at sharp angles, where their speeds can be even higher. Such impacts release huge amounts of destructive kinetic energy.



Explosions in orbit

One of the most dangerous ways in which quantities of space junk can increase is when discarded rocket stages are left in orbit with fuel still in their tanks. In some cases, liquid fuel can simply evaporate until the pressure of the gas from within ruptures the rocket's hull. In others, the rocket's internal structure can deteriorate over time due to various stresses (such as the continued expansion and contraction driven by sharp temperature changes in space). Eventually, the barrier between tanks can break down, enabling different rocket propellants to mix with dramatic results - explosions that have the potential to fling out chunks of shrapnel with different masses and speeds into orbit.

An even more impressive collision took place in 2009, when Iridium 33 - part of the US satellite telephone network - collided with the defunct Russian communications satellite Kosmos-2251 at high speed. The two satellites were travelling almost perpendicular to each other and, in the months that followed, NASA tracked a spreading field of more than 2,000 substantial debris fragments. In March 2012, astronauts aboard the International Space Station were forced to take shelter, ready for an emergency return to Earth, as a fragment of the Russian satellite passed nearby.

Various space agencies have also done their best to add to the problem from time to time. The earliest example of deliberate orbital littering came with Project West Ford in 1963 - an attempt to scatter a ring of almost 500 million tiny magnetic needles around the Earth. It was thought this would form an artificial ionosphere - a reflecting layer for bouncing military signals between distant locations. Other shocking examples include the deliberate destruction of satellites during anti-satellite missile tests. China's destruction of its Fengyun-1C satellite during a 2007 weapons trial still holds the ignominious record as the source of the largest amount of catalogued debris.

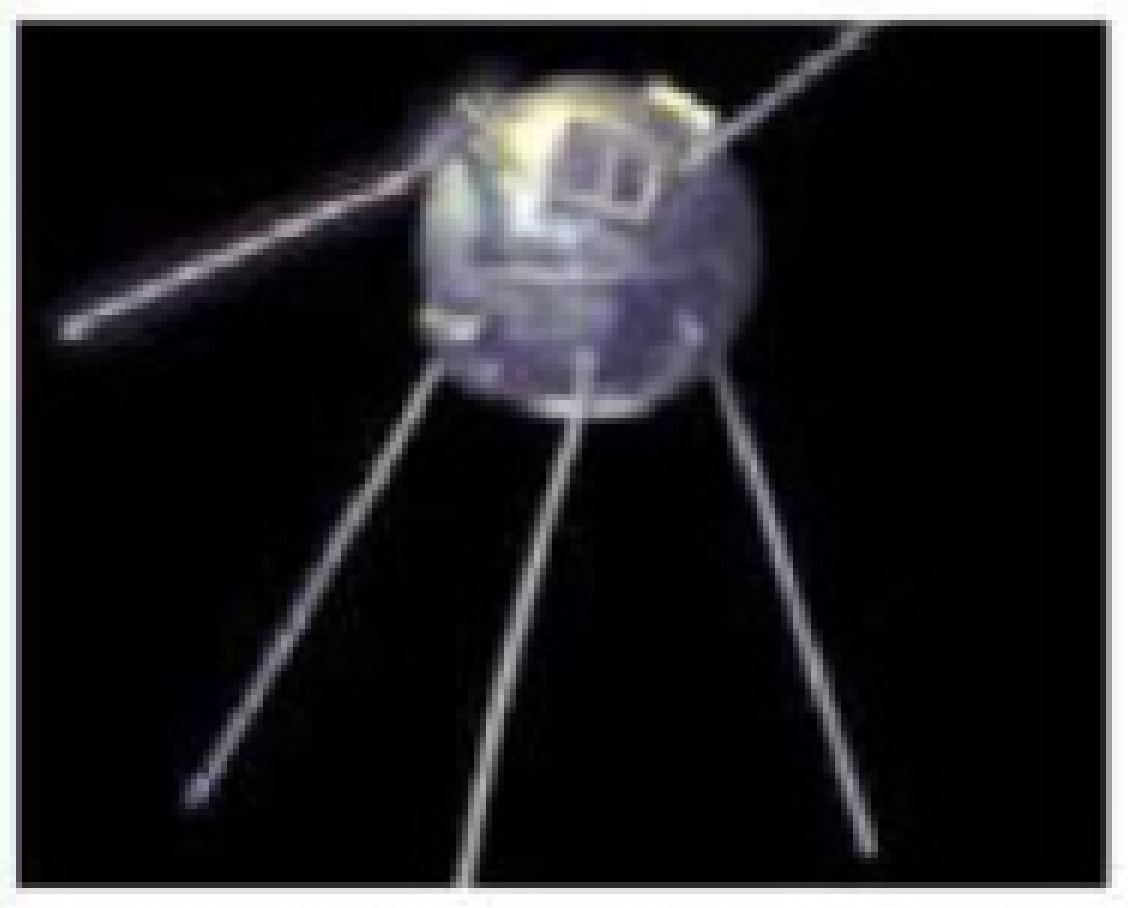
Fortunately Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere or exosphere. Although objects in orbit can usually be considered as outside the atmosphere, the thin shell of gases has no abrupt edge - instead it extends out for thousands of kilometres, growing ever thinner. Friction caused by collisions with these sparse gas molecules gradually slows the orbits of satellites, dropping them closer to Earth, where they experience increasing friction. As a result, with no external intervention, most satellite orbits inevitably decay and objects re-enter the atmosphere. However, atmospheric drag is only really effective at clearing out orbits below about 800 kilometres (500 miles).

In the early days of space exploration, engineers mistakenly assumed that orbital decay would drain debris from orbit quicker than it could accumulate, but they reached this conclusion without considering two significant factors. The first of these is simply the increased accessibility of space and the number of satellite launches. The second, and more alarming problem, is the so-called Kessler effect.

Named after NASA scientist Donald Kessler, who in the 1970s predicted the development of a fully

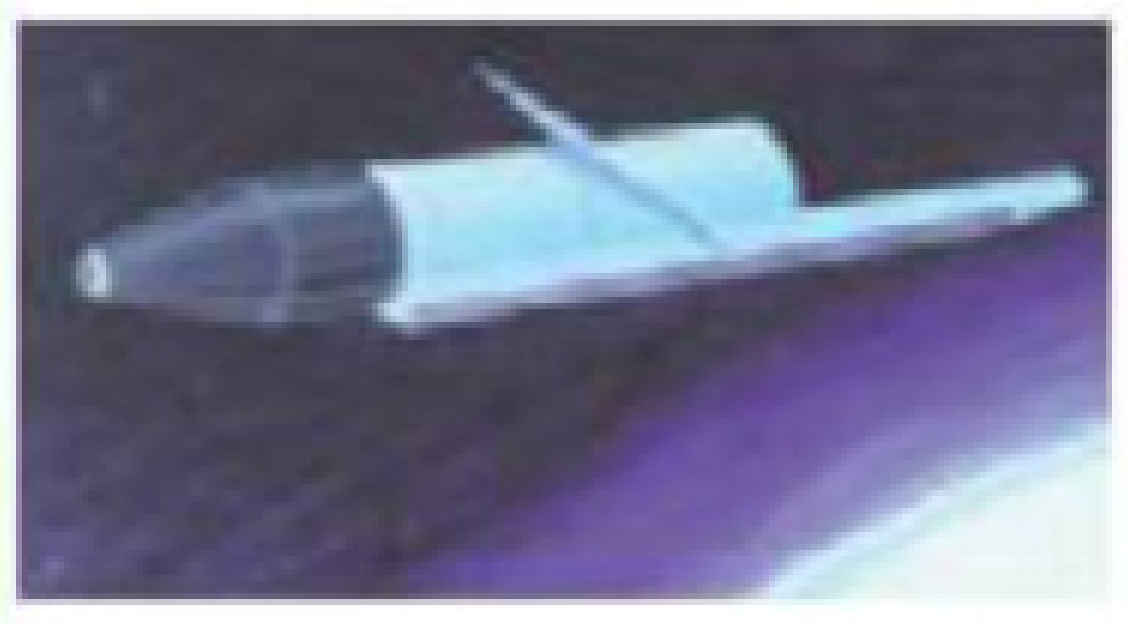
> "Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere"

Left in space



Vanguard 1

The oldest piece of space junk still in orbit is Vanguard 1, the second US satellite. It stopped transmitting signals to Earth in 1964, but is likely to remain in orbit for another two centuries.



Orbiting reactors

RORSAT was a series of spy satellites launched by the Soviet Union between 1967 and 1988. While the satellites have re-entered the atmosphere, their reactor cores were ejected into higher orbits.

Lost tools

Space Shuttle astronauts had to cope with the embarrassing sight of a number of tools drifting away into space, including wrenches, pliers and on one occasion an entire toolbag!

Space junk through the years

Since our first forays beyond the Karman line, around 100 kilometres (60 miles) above sea level, we've sent an exponential stream of objects, instruments and spacecraft into various levels of Earth orbit. For the best part of that time, we've not even thought about the mess we've been making up there or the consequences of space junk in the future.

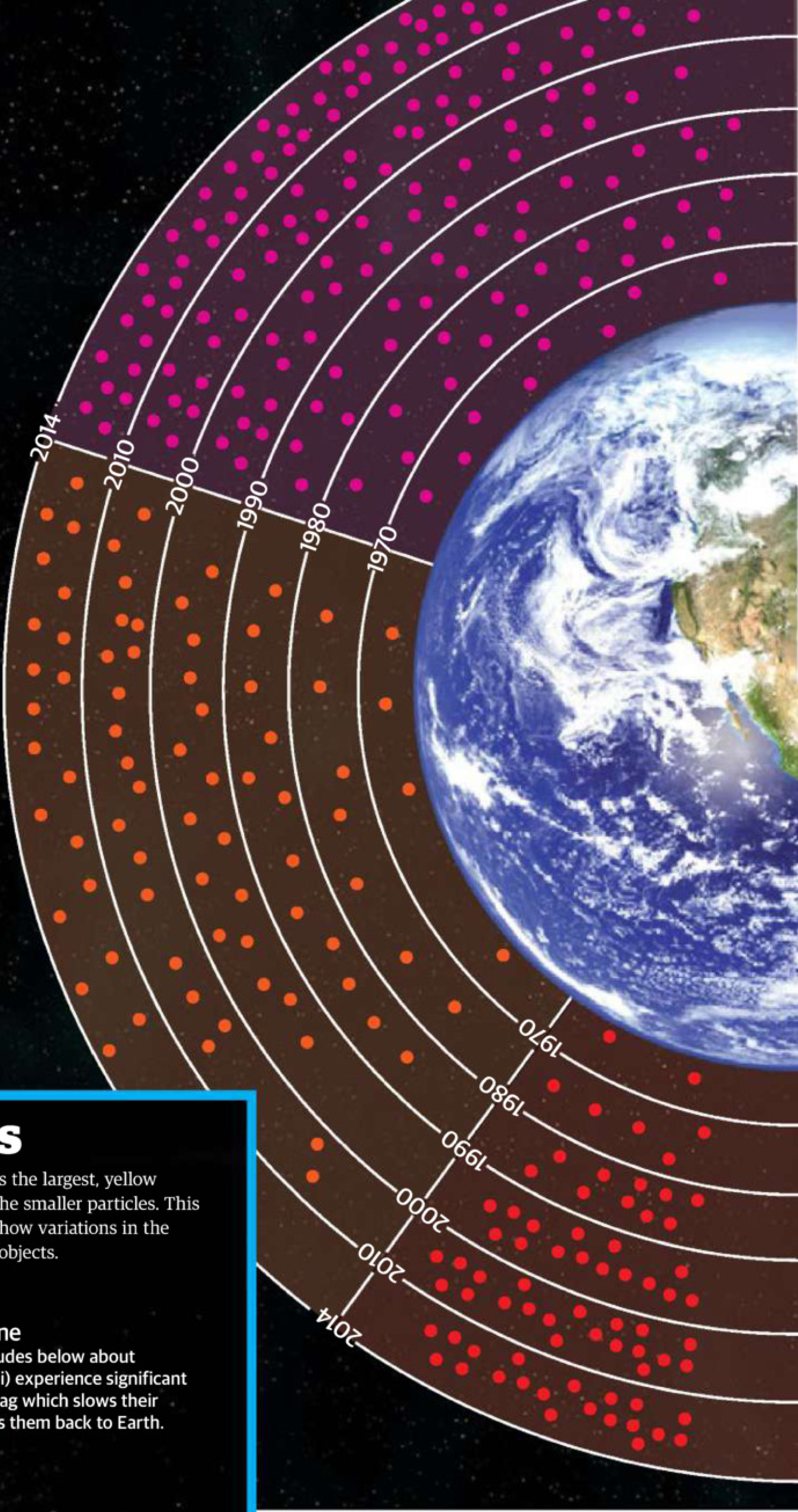
Both the amount and different types of junk has increased dramatically in the last 30-40 years since the Apollo missions. Here's the kind of dangerous scrap every new space mission faces in orbit today...

Key

- Each dot represents 100 objects with a diameter of more than 10cm

Type of debris

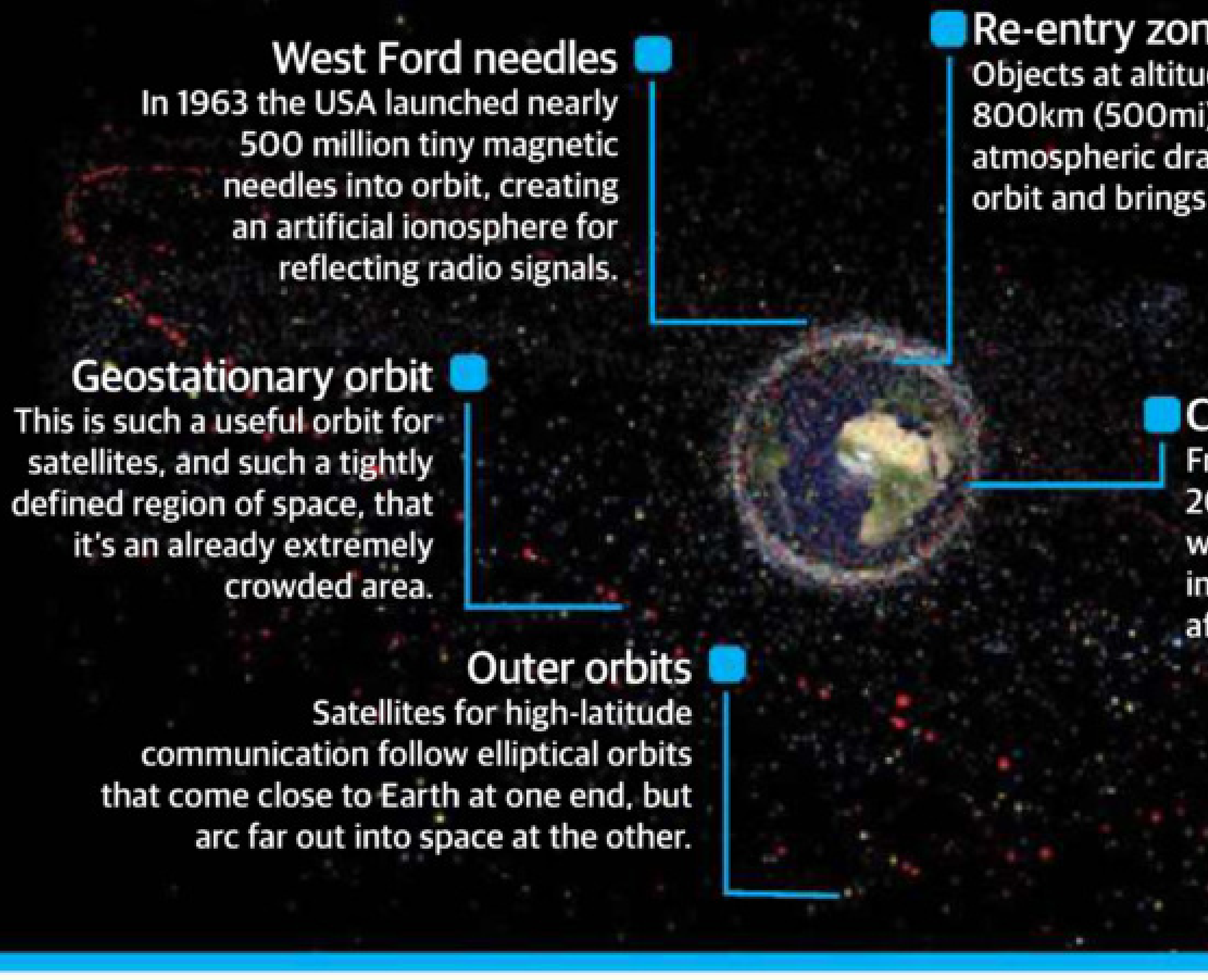
🟥 Payloads
🟦 Payload debris
🟩 Rocket mission-related objects
🟪 Rocket debris
🟧 Rocket bodies



Earth's deadly debris zones

This artist's impression attempts to visualise the crowded space around the Earth, highlighting the busiest regions, including LEO and geostationary orbits. Different sizes of object are represented in various colours: red is the largest, yellow intermediate and blue the smaller particles. This view only attempts to show variations in the distribution of orbiting objects.

Key 🔴 > 10cm 🟡 > 1cm 🔵 > 1mm



West Ford needles
In 1963 the USA launched nearly 500 million tiny magnetic needles into orbit, creating an artificial ionosphere for reflecting radio signals.

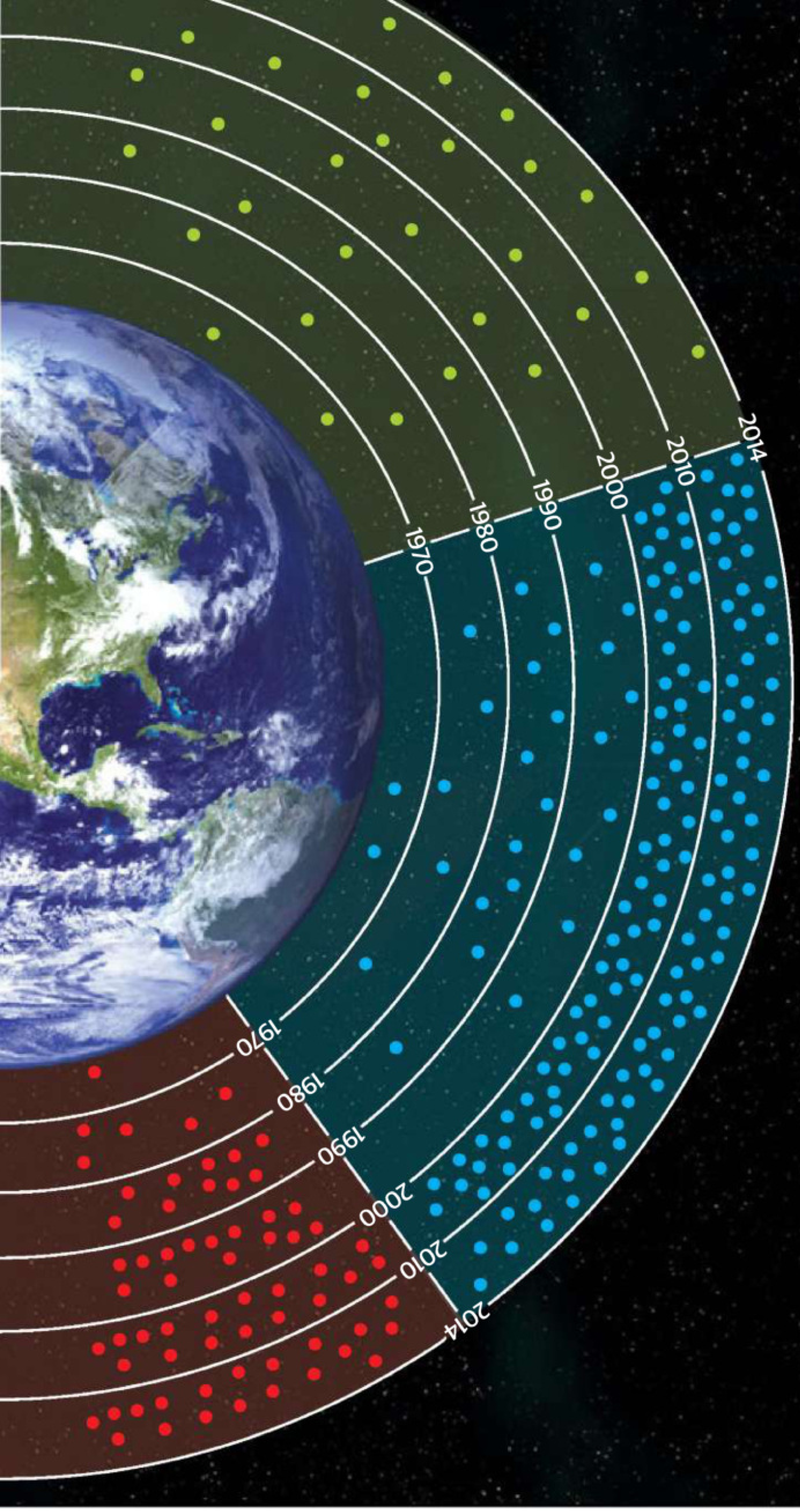
Re-entry zone
Objects at altitudes below about 800km (500mi) experience significant atmospheric drag which slows their orbit and brings them back to Earth.

Geostationary orbit
This is such a useful orbit for satellites, and such a tightly defined region of space, that it's an already extremely crowded area.

Collision aftermath
Fragments from the 2009 satellite collision were scattered along two intersecting orbital bands after spreading out.

Outer orbits
Satellites for high-latitude communication follow elliptical orbits that come close to Earth at one end, but arc far out into space at the other.

blown debris belt around the Earth by the turn of the millennium, Kessler syndrome is an effect in which, once the debris belt has reached a certain critical density, an initial collision between two large objects can give rise to a cascade, or avalanche, effect. This results in shrapnel being flung out from the first collision, hitting other objects in nearby orbits and generating yet more debris. Kessler was the first to recognise that one of the crucial factors controlling the density of objects was the rate of collisions between them, since a single high-energy collision shattering an asteroid could produce countless



Space junk: the figures

22,000

The number of large objects less than 10cm across being tracked in Earth orbit by NASA's GEODSS system

500K

Statistical estimate of the mid-sized fragments (1-10cm across) in orbit around Earth

3mm

Size of the smallest debris fragments that can be seen by Earth-based radar monitoring

1 in 200

NASA's upper risk limit to the chances of a collision with a piece of debris on a mission

13,000

The estimated number of close calls that occur every week

8,211kg

The mass of the Envisat satellite stranded in a crowded region of Low Earth Orbit

3,000

Number of trackable debris pieces created by the 2007 anti-satellite test

42,120km/h

Speed of the 2009 collision between Iridium 33 and Kosmos-2251

fragments, each of which, though small, might potentially be fatal to a spacecraft.

This is the kind of event dramatised in that pivotal sequence from *Gravity* and its overall result could be to render large areas of Earth orbit inaccessible for many years. While it's unlikely that a Kessler cascade could block access to space completely, it could make it harder to reach certain types of useful orbit and limit the operational lifetime of satellites after their deployment. These are all factors that could significantly affect everyday technologies such as satellite navigation, telephony and broadcasting, as well as limiting scientific missions such as Earth remote sensing and orbiting astronomical telescopes.

So, in little more than five decades of spaceflight, we've already reached a situation in which space junk is a very real threat. It's one that's only likely to get worse in the future unless we take global action not just to improve our littering habits, but also to remove the material that's already there.

Satellites are increasingly being designed with the facility to boost into a safe, remote graveyard orbit at the end of their useful lives, or to deliberately deorbit, ensuring a safe, controlled breakup in the atmosphere. Efforts have also been made to limit the dangers from potentially explosive debris left in orbit. There's even talk of regulating commercial satellite companies with a 'one up, one down' rule, so it's in their financial interest to ensure defunct spacecraft are safely and cleanly dealt with. The International Telecommunication Union (ITU), responsible for regulating comsats in geostationary orbit, has been particularly keen to ensure this valuable and very precise orbit is maintained for future use.

So, how can we clear out all the junk that's already up there? Various ideas have been put forward, including automated tug spacecraft capable of boosting geostationary satellites into a graveyard orbit, or even returning them to Earth. However, this kind of mission would only really be practical for handling the largest pieces of debris - shifting material between orbits would require large amounts of propellant, so the tug design itself would require an infrastructure for refuelling in orbit.

An ingenious alternative, developed by researchers at Texas A&M University, is the Sling-Sat - a fuel-efficient mission that would involve a spinning satellite briefly capturing debris before flinging it away on a safe path towards de-orbit. Each interaction with a debris particle would increase the satellite's momentum, enabling it to remain in operation for a long period of time.

Dealing with the countless smaller debris fragments is a much greater challenge, so for practical reasons any clean-up operations will almost certainly be limited to certain specific clusters of small debris, such as those left behind by Project West Ford.

Many proposals involve deploying the space-based equivalent of a butterfly net. In February 2014, a joint US-Japanese satellite launched into orbit carrying a prototype for one such design. The Space Tethered Autonomous Robotic Satellite 2 (STARS-2) mission involves the deployment of a small subsatellite at the end of a 300-metre (984-foot) tether cable. Using the same principle as a bicycle dynamo, this tether will generate electric current as it passes through Earth's magnetic field and the resulting electromagnetic field around it should attract nearby debris particles, rather like a balloon with a static charge attracting dust. If the trial goes according to plan, a full-scale version could be in operation by 2019.

Another widely touted alternative is known as the laser broom, involving firing a medium-powered laser from the ground towards the front of debris particles. Working on the same principle as solar sail propulsion, the laser would apply a tiny braking force to the target object, gradually draining its momentum and pushing it onto a new orbit. Studies suggest that a laser broom could adjust the orbit of small objects by a couple of hundred metres over a few hours - enough to avoid potential collisions, while repeated use could nudge an object towards eventual deorbit. The accurate targeting of such small and fast-moving objects would be a major challenge so, for the moment at least, laser brooms might be most appropriate as a last line of defence for space stations.

One thing, it seems, is certain - with new players entering the field of space exploration and the valuable real estate of Earth orbit becoming ever more crowded, space junk isn't a problem that's about to go away any time soon - it's quite literally an accident waiting to happen.

Clean-up operation

Grappling in space
This artist's concept for a tug spacecraft uses a simple robot arm to grasp the target satellite, most of which are designed with grappling handles or docking points.

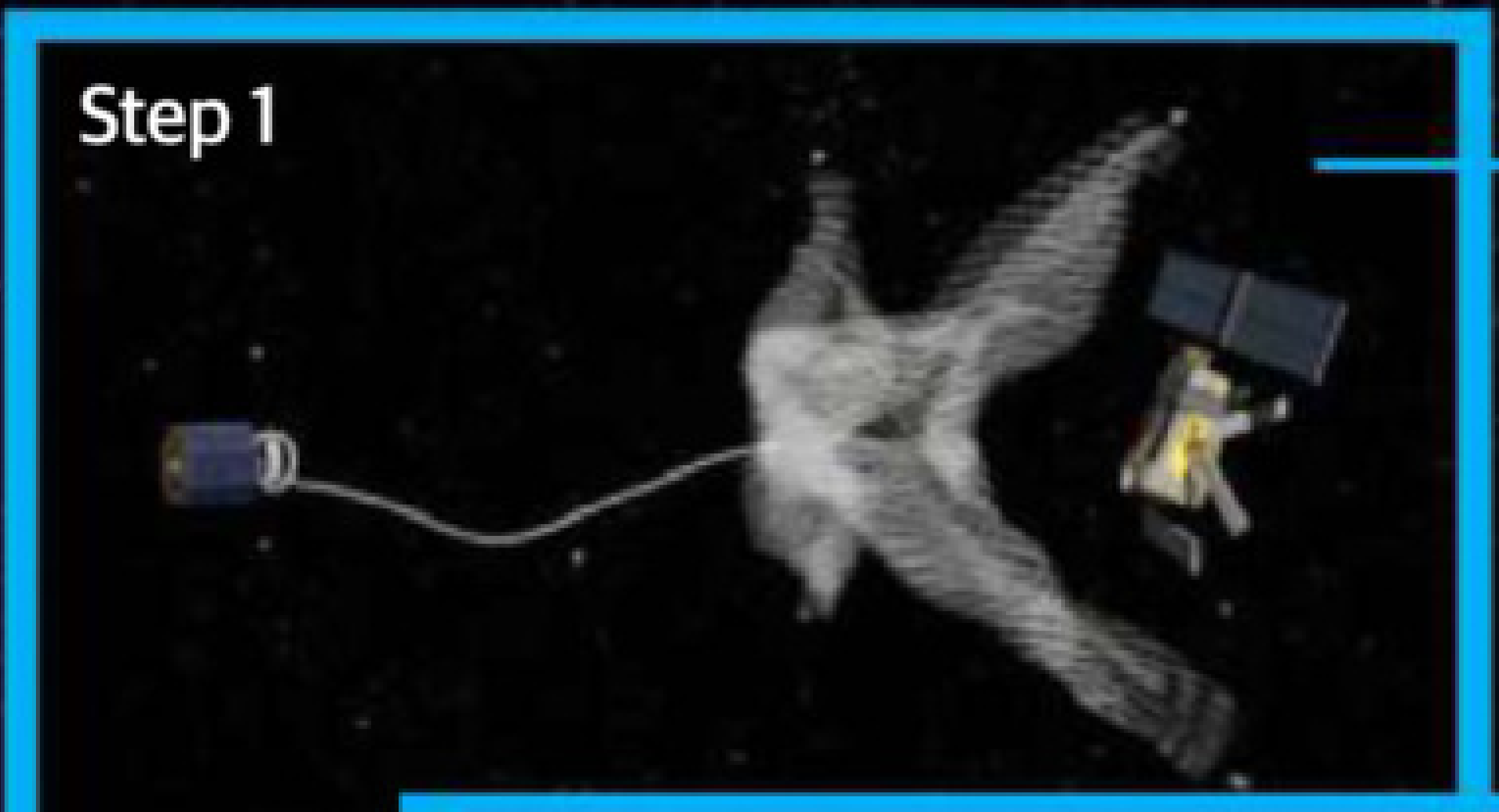
Final approach
Capturing a satellite from orbit requires a slow and accurate rendezvous for final docking, achieved using either radar or laser ranging.

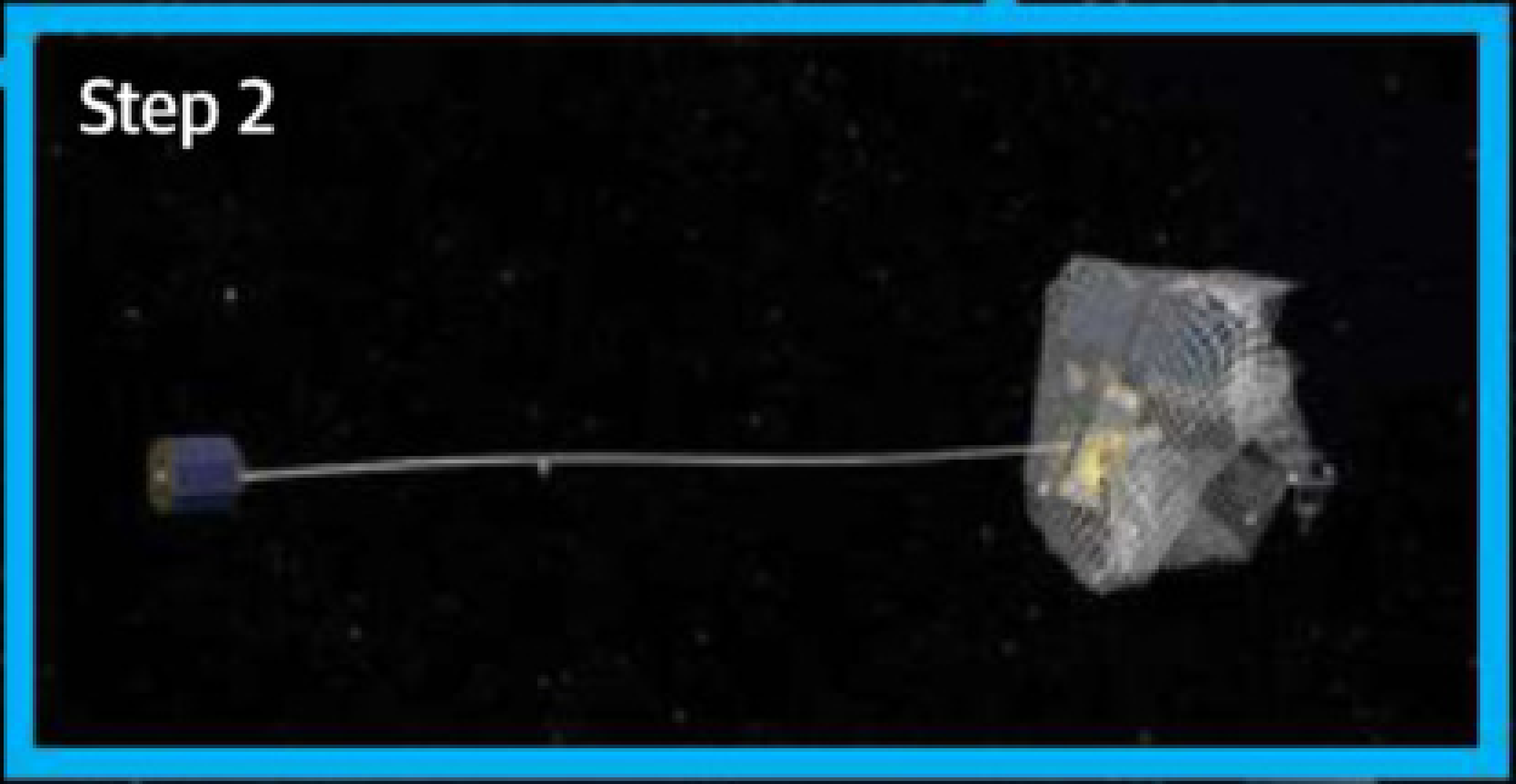
Phasing
In the phasing stage of the mission, precisely timed rocket engine burns boost the apogee (highest point) of the tug's orbit towards its target.

Orbit & rendezvous
As the tug closes in on its target satellite, further precisely timed burns match the direction and speed of the two craft.

Commissioning

Launch
A purpose-built space tug satellite is initially launched into a circular LEO with an altitude of about 300km (186mi).


Step 1

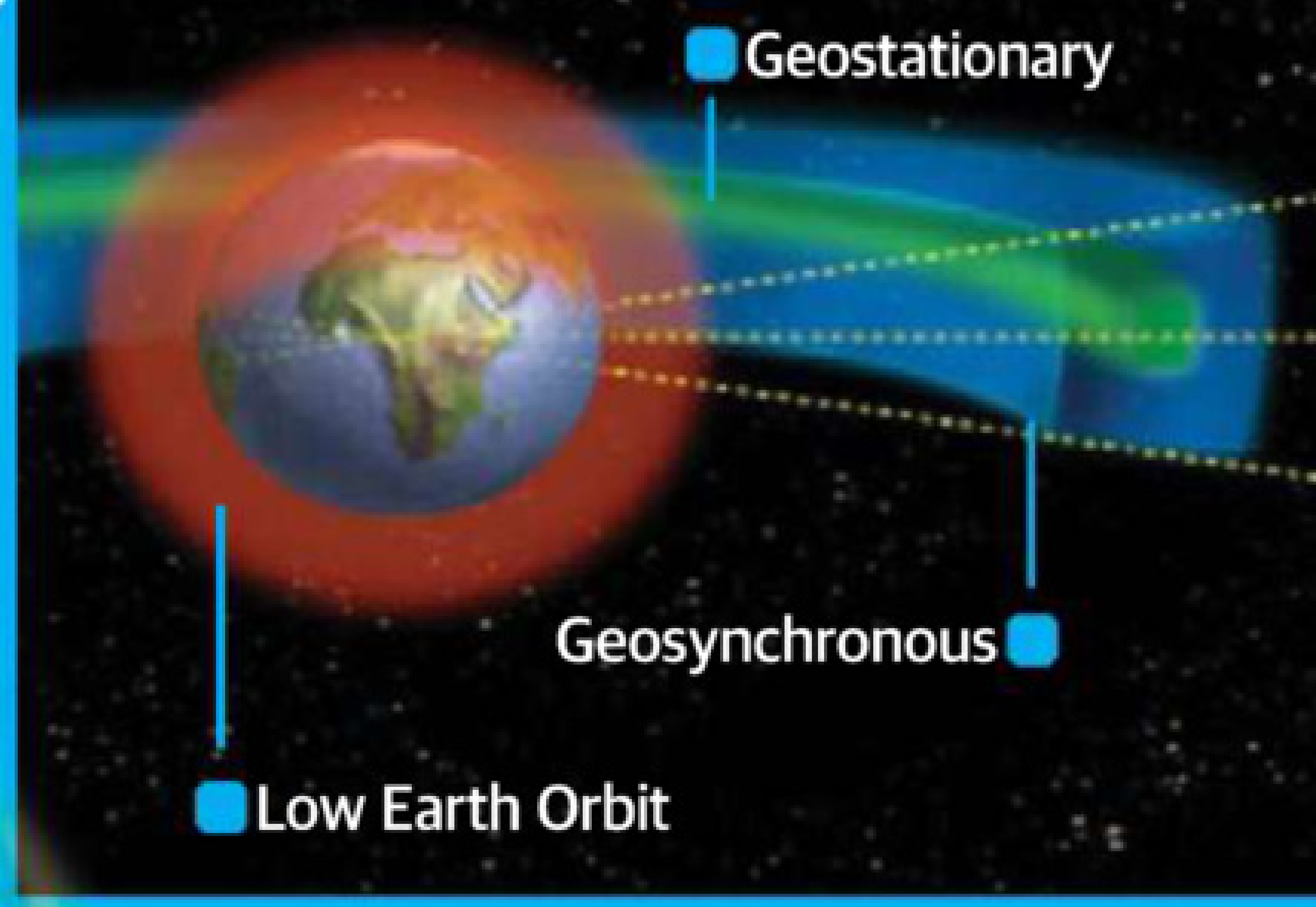

Step 2

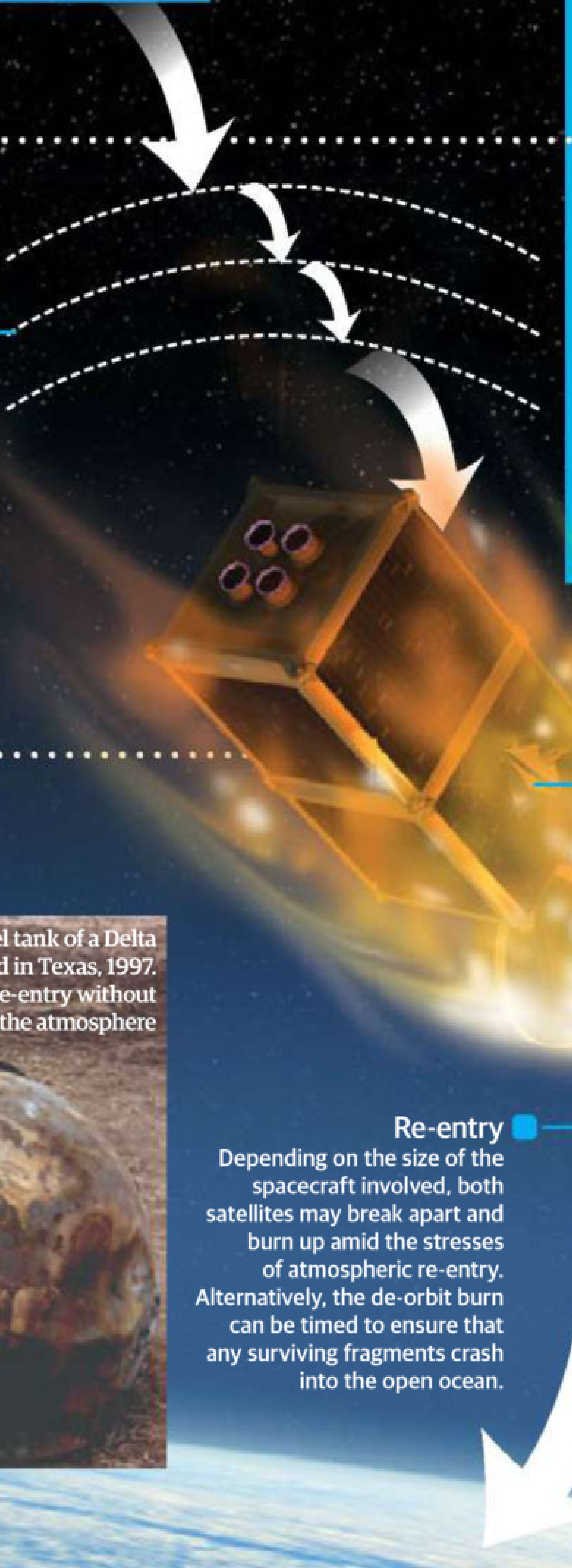
Trawling in orbit
Another possible way of capturing a satellite, illustrated in these two steps, involves the deployment of a large net or basket at the end of a long, flexible tether. Once the satellite is secured, the final phase of the mission can begin.

Protected orbits?

Since 1993, most of the world's major space agencies have been members of the Inter-Agency Space Debris Coordination Committee (IADC), a co-operative effort to research the effects of space debris and look at ways of resolving the problem.

One of their key proposals, first outlined in 2002, is the creation of protected orbital regions – zones where special efforts would be made to avoid debris creation – and to remove defunct satellites once their useful lifetime is at an end. The two key zones are LEO (defined as everything below an altitude of 2,000 kilometres or 1,243 miles) and the geosynchronous region covering a swathe 400 kilometres (249 miles) deep and 30 degrees wide around the exact geostationary altitude of 35,786 kilometres (22,236 miles). Geostationary transfer orbits used by satellites on their way to the geosynchronous region, IADC argues, should also be protected.





Perigee lowering
The tug spacecraft reorients itself in space so that engine burns gradually slow its orbital momentum and lower its perigee (closest point to Earth).

De-orbit burn
With the perigee skimming the thicker layers of Earth's atmosphere, a final engine burn puts the tug and its cargo on target for re-entry.

Re-entry
Depending on the size of the spacecraft involved, both satellites may break apart and burn up amid the stresses of atmospheric re-entry. Alternatively, the de-orbit burn can be timed to ensure that any surviving fragments crash into the open ocean.

The main 250kg (551lb) fuel tank of a Delta 2 launch vehicle that landed in Texas, 1997. The vehicle survived re-entry without completely burning up in the atmosphere

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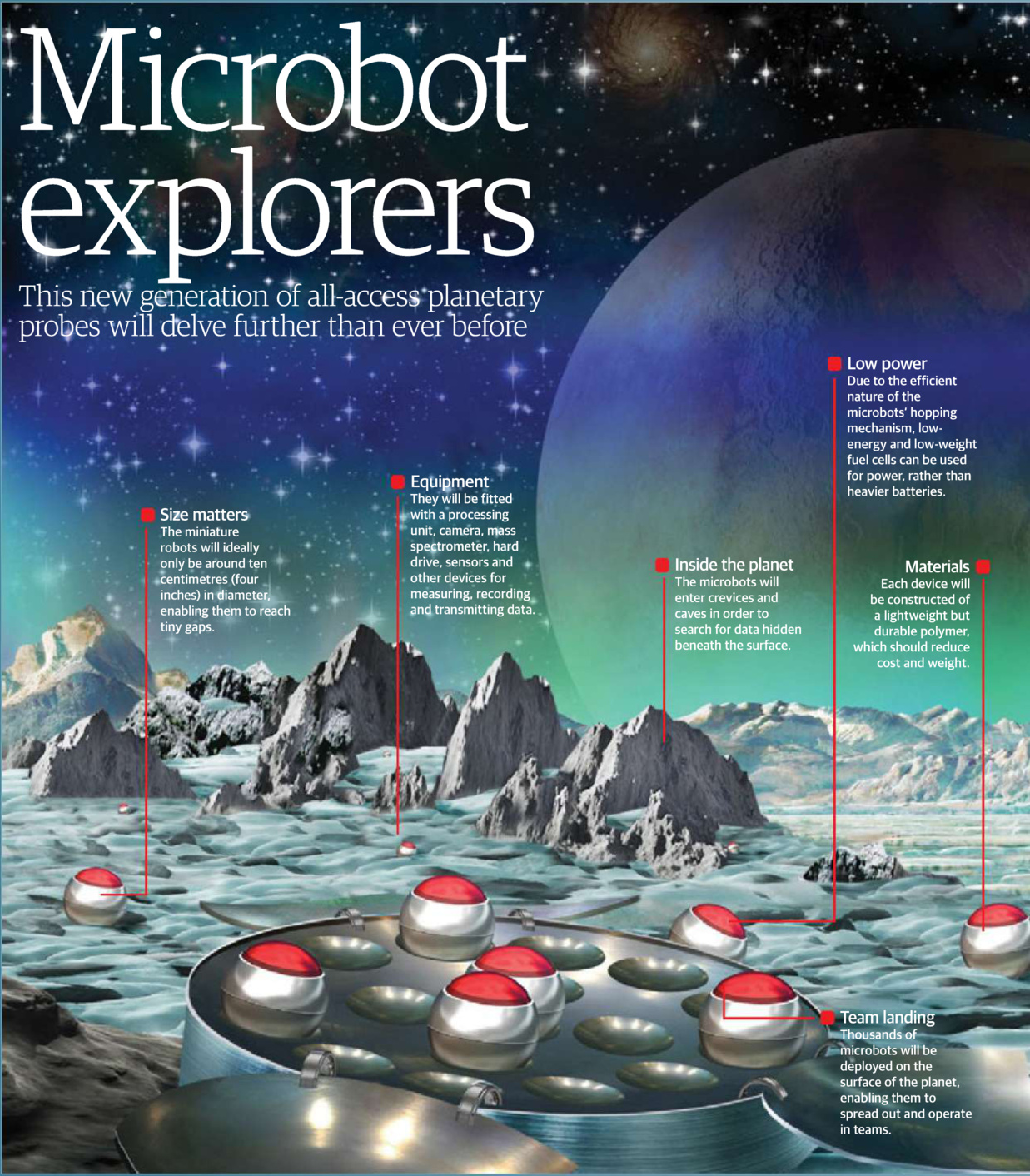
Microbot explorers

This new generation of all-access planetary probes will delve further than ever before



Low power
Due to the efficient nature of the microbots' hopping mechanism, low-energy and low-weight fuel cells can be used for power, rather than heavier batteries.

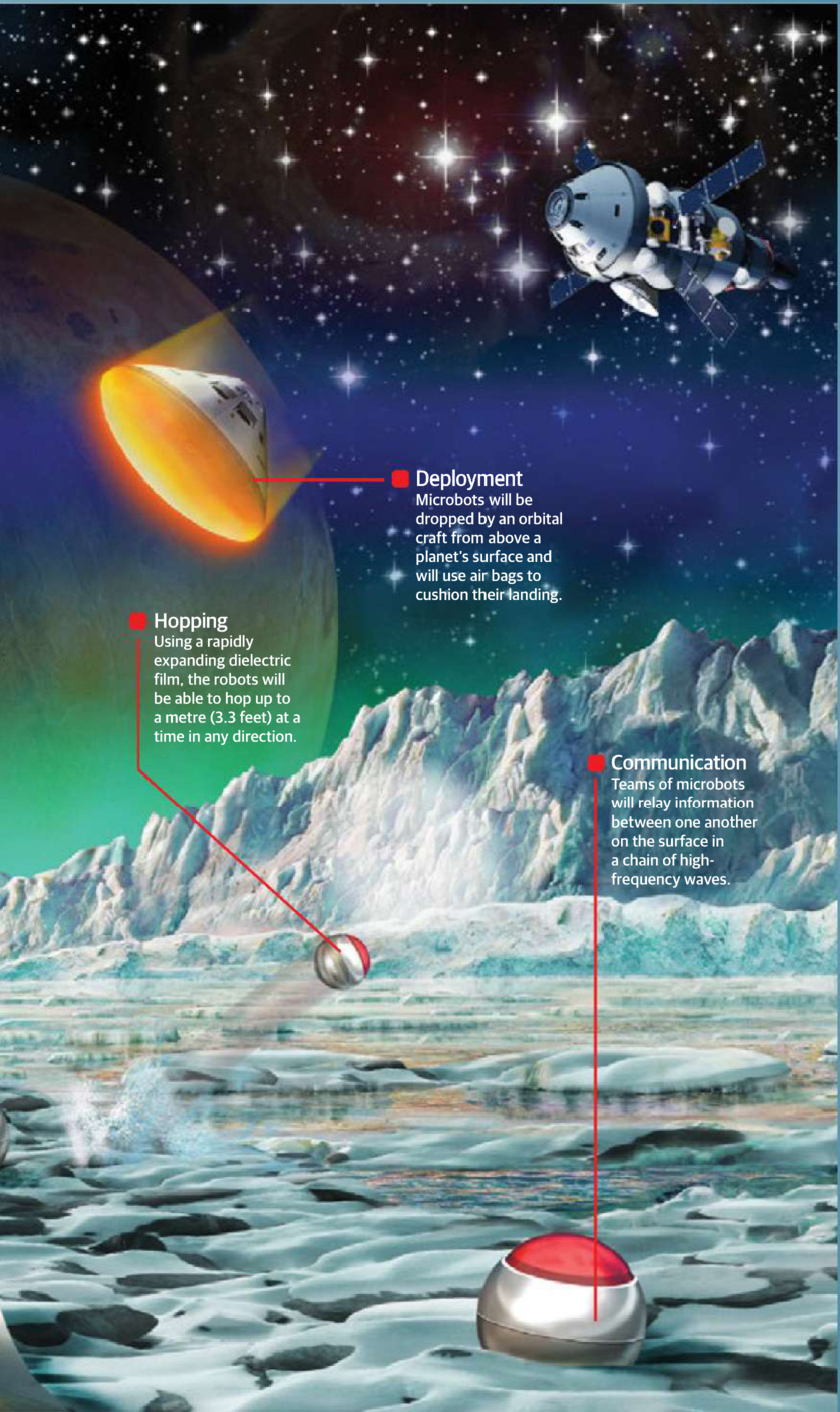
Equipment
They will be fitted with a processing unit, camera, mass spectrometer, hard drive, sensors and other devices for measuring, recording and transmitting data.

Size matters
The miniature robots will ideally only be around ten centimetres (four inches) in diameter, enabling them to reach tiny gaps.

Inside the planet
The microbots will enter crevices and caves in order to search for data hidden beneath the surface.

Materials
Each device will be constructed of a lightweight but durable polymer, which should reduce cost and weight.

Team landing
Thousands of microbots will be deployed on the surface of the planet, enabling them to spread out and operate in teams.



Deployment
Microbots will be dropped by an orbital craft from above a planet's surface and will use air bags to cushion their landing.

Hopping
Using a rapidly expanding dielectric film, the robots will be able to hop up to a metre (3.3 feet) at a time in any direction.

Communication
Teams of microbots will relay information between one another on the surface in a chain of high-frequency waves.

From the moment the Soviet Union landed the Lunokhod 1 lunar rover on the Moon in November 1970, scientists and astronomers have been working tirelessly to create more-efficient and effective methods for searching a planet's surface. We have seen rovers, landers and probes, but a team from the Department of Mechanical Engineering at MIT are working on microbots, the next generation of planetary investigators.

These tiny spherical robots – often no larger than a baseball – are able to hop, bounce and roll around the surface of a planet, get into crevices and negotiate obstacles in ways that traditional rovers are unable to.

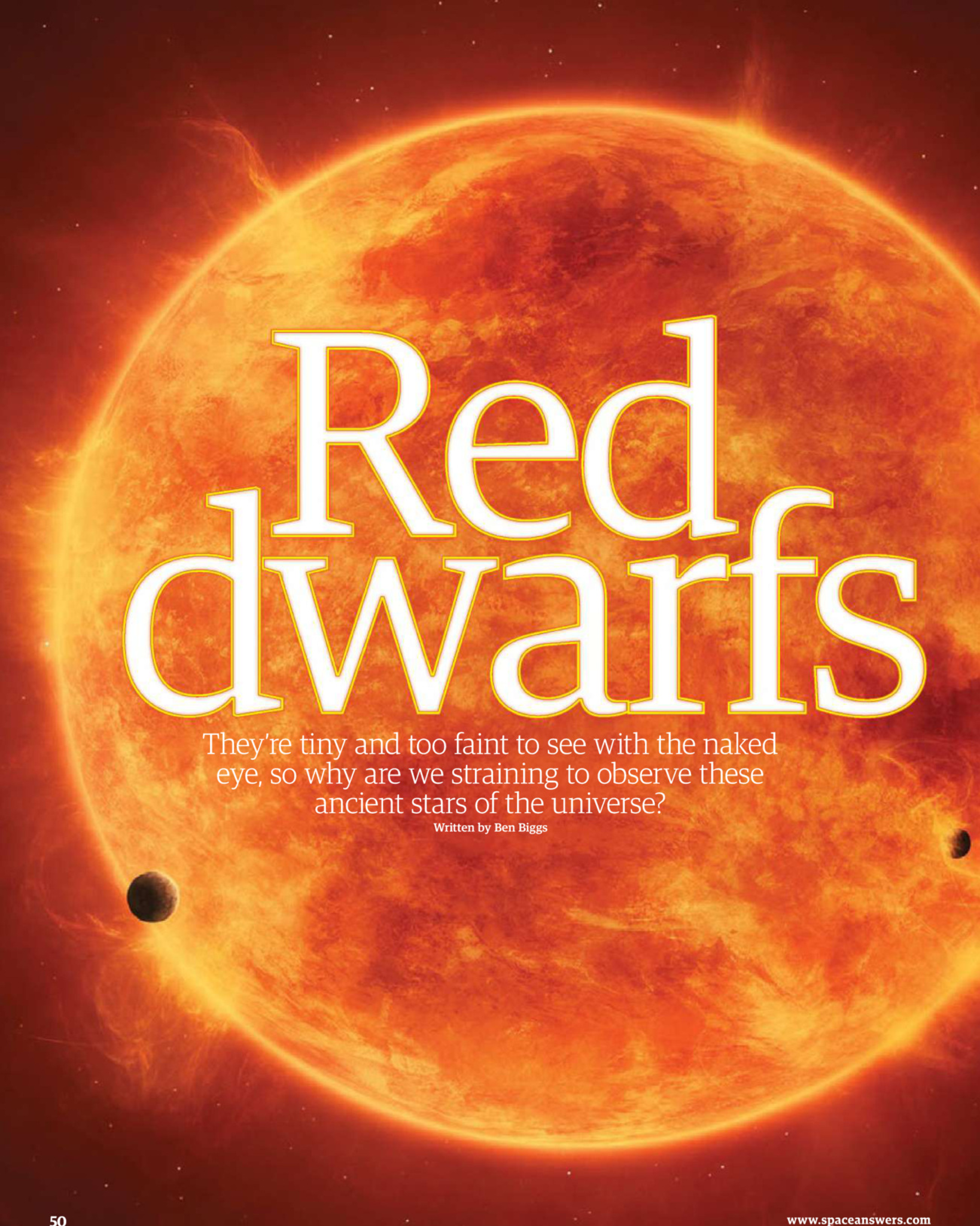
Within the next ten to 40 years, engineers are hoping to reduce microbots to just ten centimetres (four inches) in diameter and have them weighing no more than 100 grams (3.5 ounces), so they are able to get themselves into hard-to-reach places. They would be constructed of lightweight polymers and carry miniaturised scientific equipment for research. Many of the key components encased in the machines will be around the size of a coin, with the mass spectrometer measuring just 0.6 cubic centimetres (0.04 cubic inches) and the 4GB hard drive only just larger than a two-pence piece or a dollar coin.

The idea is to deploy hundreds of microbots on the surface of a planet, using an orbital craft to carry them and an airbag system to ensure they're intact when they hit the planet's surface. From there, the microbots will spread out in teams, scouring the planet's surface and finding their way into lava tube caves. This will enable in-situ examinations of the planet's composition, history and chemical structure. They will then send this information back to the surface, where it can be stored and communicated to teams back on Earth. The microbots would sometimes have to work in a relay to get the information back to the surface as electromagnetic waves struggle to get through rocky structures. This means that the information would be transmitted using high-frequency waves, jumping from bot to bot until the signal is eventually able to be picked up on the surface.

A Dielectric Elastomer Actuator – an elastic dielectric film placed between stretchy electrodes – creates the hopping movement of the microbots. When current is passed through this, the electrodes are stimulated and laterally expand the film. This rapid expansion enables a microbot to hop on its bistable leg and travel across the planet's surface, easily traversing obstacles such as rocks. Each hop could take a microbot as far as a metre (3.3 feet), which would enable it to travel across dozens of metres every day, collecting important scientific information as it goes.

Mars would be one of the first obvious ports of call for this generation of planetary explorers. There has been an awful lot of analysis of the Red Planet recently, but the opportunity to go deeper than ever before is one the team at MIT will find hard to pass up. The Moon, with its pock-marked surface, will be another key area for the microbots to be deployed, but any planet or satellite with an inhospitable, rocky surface will be on the radar for these access-all-areas robots.

© Adrian Chesterman



Red dwarfs

They're tiny and too faint to see with the naked eye, so why are we straining to observe these ancient stars of the universe?

Written by Ben Biggs

Space is no place for the agoraphobic: our Solar System alone is so vast and empty it makes the open sprawl of the original American prairie seem like the inside of a small cardboard box. The technology that enables us to see massive objects from billions of light years away tends to make us fixate on the really big stuff in space, such as R136a1, a Wolf-Rayet star found in the Tarantula nebula that's an estimated 265 solar masses and outshines our Sun with nearly nine million times its luminosity. Closer to home, just a few thousand light years away, there's VY Canis Majoris. This red hypergiant has an estimated mass of up to 35 times that of our Sun, but it's voluminous enough that if it were scaled down to fill the palm of your hand, the Sun would appear smaller than a grain of sand next to it.

We pore over and marvel at these huge and distant objects, but all the while there are millions of equally fascinating smaller stars within a stone's throw of our Solar System. You might think that these stellar relatives are so small, in comparison with the awe-inspiring stellar behemoths, that it's impossible to regard them as interesting. However, their stories are just as, if not more fascinating.

Just around the corner from the Sun is Proxima Centauri, the nearest star to our own at just over four light years away. It's an example of a red dwarf – a small star that sits on the bottom-right rung of the main sequence in the Hertzsprung-Russell diagram – a graphical tool, named after its astronomer creators Ejnar Hertzprung and Henry Norris Russell that enables scientists to classify stars according to certain characteristics such as their brightness, colour and stellar type. Red dwarf stars range in mass from a low of 0.075 up to 0.5 times the mass of the Sun and most are only a few times the diameter of Jupiter, the king of the planets in our Solar System. These pint-sized stars are made just like any other main sequence star – a cloud of dust and gas is pulled together by gravity and begins to spin. The swirling causes the material to clump closer to the centre and before too long it reaches a temperature at which fusion begins. Despite their slight size, however, their low mass means these mini stars are much more easily formed, so hugely outnumber every other star type in the Milky Way. It's possible they even make up the majority of the stellar population in other galaxies too. In fact, around 20 of the nearest 30 stars to Earth and up to three quarters of the stars in our galaxy are red dwarfs.

We've established that many of the stars in our universe not only vary in size, but in surface

> "Despite their slight size, their low mass means these mini stars are much more easily formed, so hugely outnumber every other star type in the Milky Way"

Proxima Centauri shines bright through the Hubble Space Telescope in this recent image, but it's invisible to the naked eye. It's likely to remain a main sequence red dwarf for four trillion years temperature. As a result, astronomers like to put them into categories, or spectral classes O, B, A, F, G, K, M, L, T, Y. Starting from the young, unbelievably hot blue O-type stars, the classification takes us through to stars like our Sun, the G-type yellow dwarfs, before ending at the extremely cool Y-type brown dwarfs. Of the nine classes, dubbed the Harvard Spectral Classification – a scheme named after Harvard college observatory where it was developed around 1910 – that many of the stars in our universe belong to, red dwarfs are designated as the progressively cooler M-types.

Proxima Centauri is a late M-class star with barely enough mass (12 per cent of the Sun's) to sustain the temperature and pressure necessary to create nuclear fusion at its core. It's around 200,000 kilometres (124,270 miles) in diameter, which makes it only a little larger than Jupiter – that itself has a diameter of 143,000 kilometres (88,860 miles). Like other red dwarfs, Proxima Centauri has a relatively low surface temperature in the region of 3,000 degrees Celsius (5,432 degrees Fahrenheit) and is burning through its supply of hydrogen inside and outside its core, which it formed with less rapidly.

In comparison, larger, more-heavyweight stars only manage to burn through the hydrogen found at their core before their lives are snuffed out. Since red dwarfs burn at such a low temperature, the result is that they are extremely faint – even as the closest known star to the Sun Proxima Centauri is only visible as an eleventh magnitude object, which is too faint to be seen from Earth even with binoculars. The star is even outshone by some that are hundreds, even thousands of light years away.

Red dwarfs like Proxima Centauri are both interesting and important to our understanding of the universe for several reasons. First, our own yellow dwarf (the Sun) has a volume that's proportional to its mass, because its matter behaves like gas under its immense gravity. With much lower M-class stars at the bottom end of main sequence, stellar matter is more able to resist gravity's effects and curious quantum influences come into play. Matter is said to be degenerate in these stars, so although Proxima Centauri is only about 1.5 times larger than Jupiter, it has over 120 times the mass of the gas giant.

Generally speaking the lifetime of a star will increase exponentially in inverse proportion to its mass. So, the brightest and most massive stars in the universe, the hypergiant O-types of several dozen solar masses or more, might last a few million years – a cosmological blink of an eye. They burn through their nuclear fuel at a terrific rate and bloom in volume before exploding in an energetic hypernova.

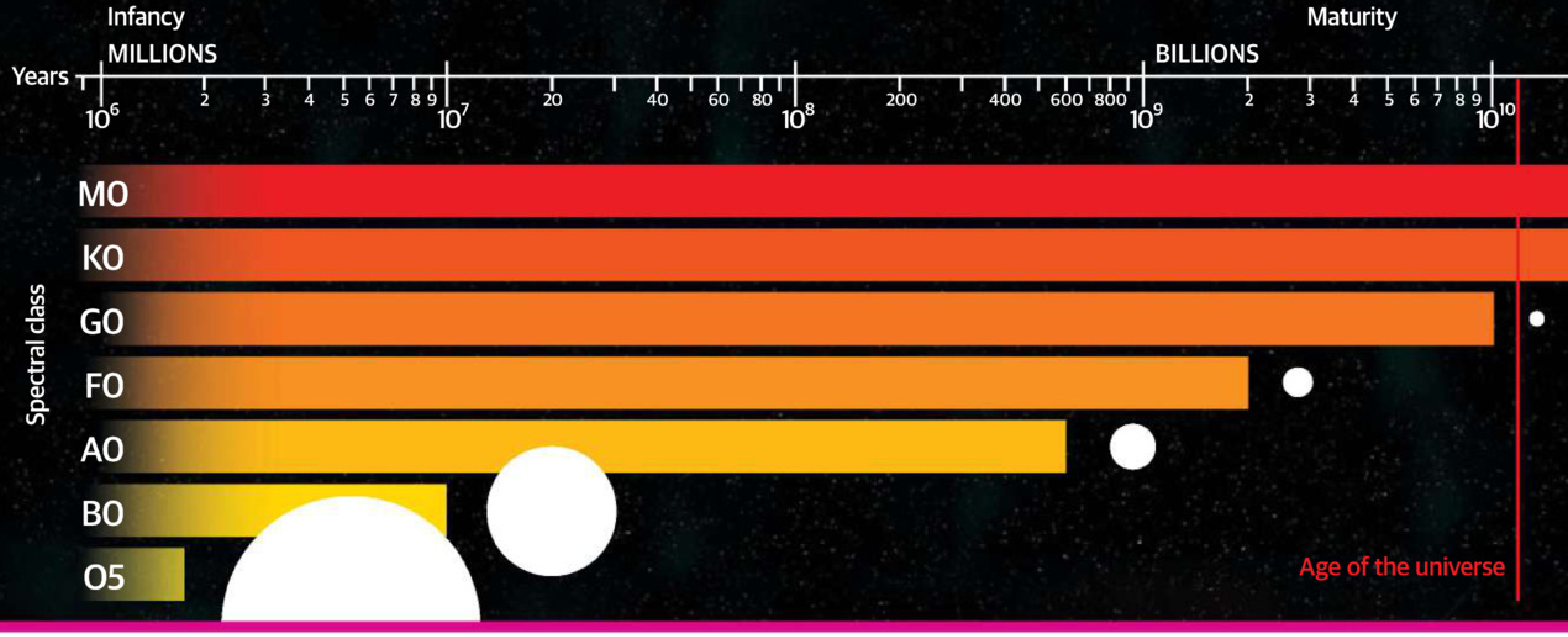
> "The sheer number of red dwarfs makes it unlikely that life hasn't existed around at least one of them"

Even stranger small stars

There is a class of substar whose mass falls below the lowest theoretical threshold at which a stellar object can sustain hydrogen fusion and so be considered a true star. Brown dwarfs straddle the gap between the biggest gas giants and smallest stars, with masses that range from about 80 times that of Jupiter down to a debated low threshold of about ten Jupiter masses. They are extremely dense, so despite being many times the mass of Jupiter, brown dwarfs are the same size as the gas giant.

The laws of quantum physics govern the huge density of some of the smallest and strangest stars in space. Neutron stars are often left by massive stars after a supernova. They can be several times the mass of the Sun, yet have a diameter of just ten kilometres (six miles).

How long do main sequence stars live?

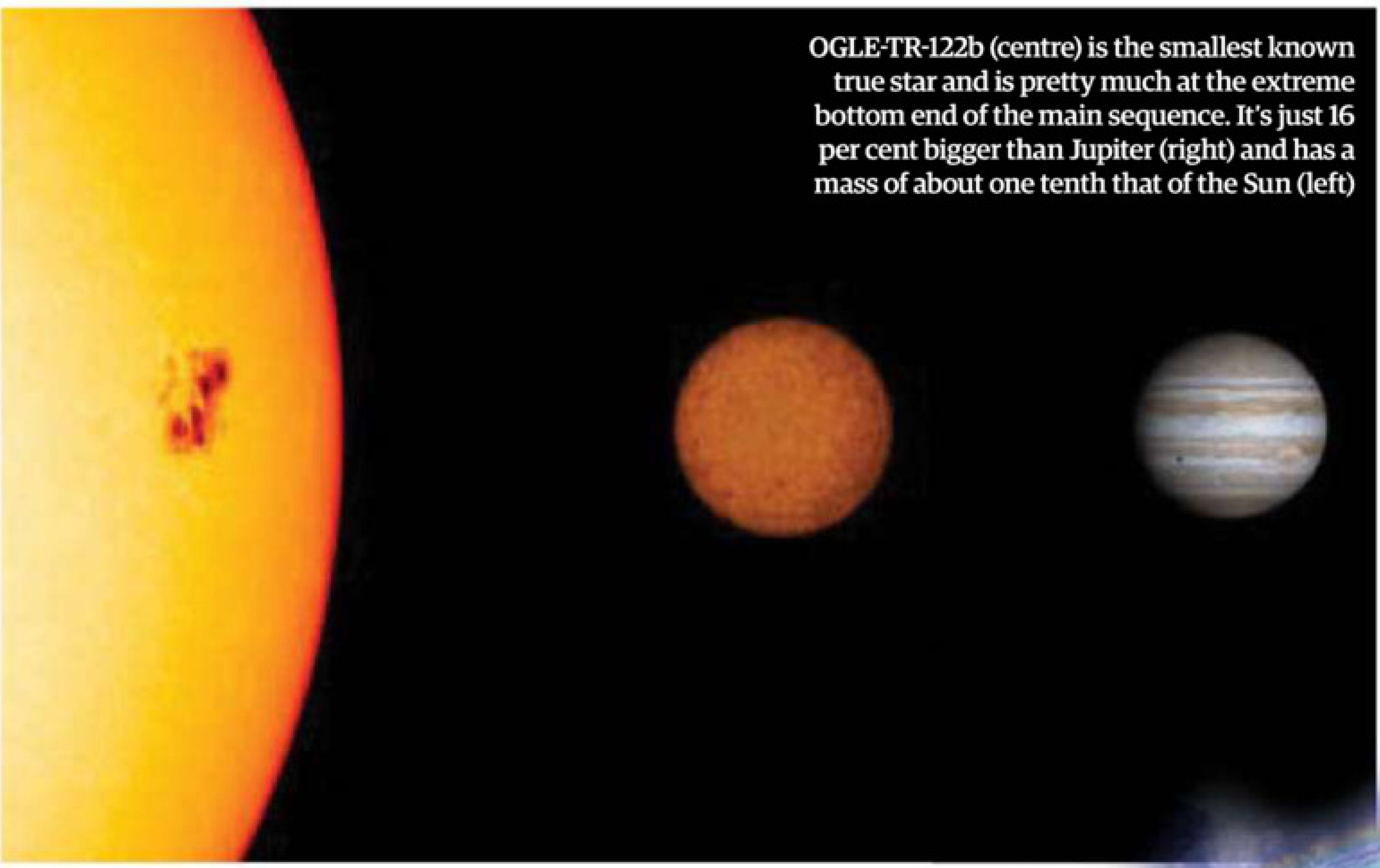


Our G-type Sun, which has been around for five billion years or so, will continue to use its remaining hydrogen for around another five billion years before it throws off its outer layers in huge mass ejections, leaving nothing but the white hot ember of its core behind to be seen.

We can see examples of stars at these final stages of their evolution throughout our galaxy. However, we're unable to see any dead or dying red dwarfs, because their lifetimes can run into hundreds of billions, even trillions of years, many times older than the current age of the universe. So the ultimate fate of these slow burners - gradually fading away as a white dwarf - is currently all theory.

In recent years known red dwarf stars have become the go-to objects for exoplanet-hunting telescopes, partly because there are so many of this type of star to observe and scientists think there is at least one exoplanet orbiting every red dwarf in our galaxy. Their long lifespans and stability also make it more likely that complex life could develop on an exoplanet orbiting a red dwarf. It took over 500 million years for the very simplest of single-celled life forms to appear after the formation of the Earth. Given that as an analogue, we're unlikely to find life on a planet orbiting an O-, B-, A- or even some F-type stars, whose lifespans tend to be far too short to nurture any form of life.

New exoplanet-spotting techniques and more-powerful telescopes are revealing planets all the time. Just recently, a NASA researcher discovered the first Earth-sized planet in the habitable zone of another system, one of five orbiting an M1-type red dwarf star. While it's the subject of some debate as to whether a planet that orbits this close to a red dwarf can also play host to life, the sheer number of red dwarfs makes it unlikely that life hasn't existed around at least one of them at some point in history. In any case, as one of the most numerous and yet difficult-to-observe types of star in the universe, these red dwarfs can only become more interesting to astronomers over time. ■

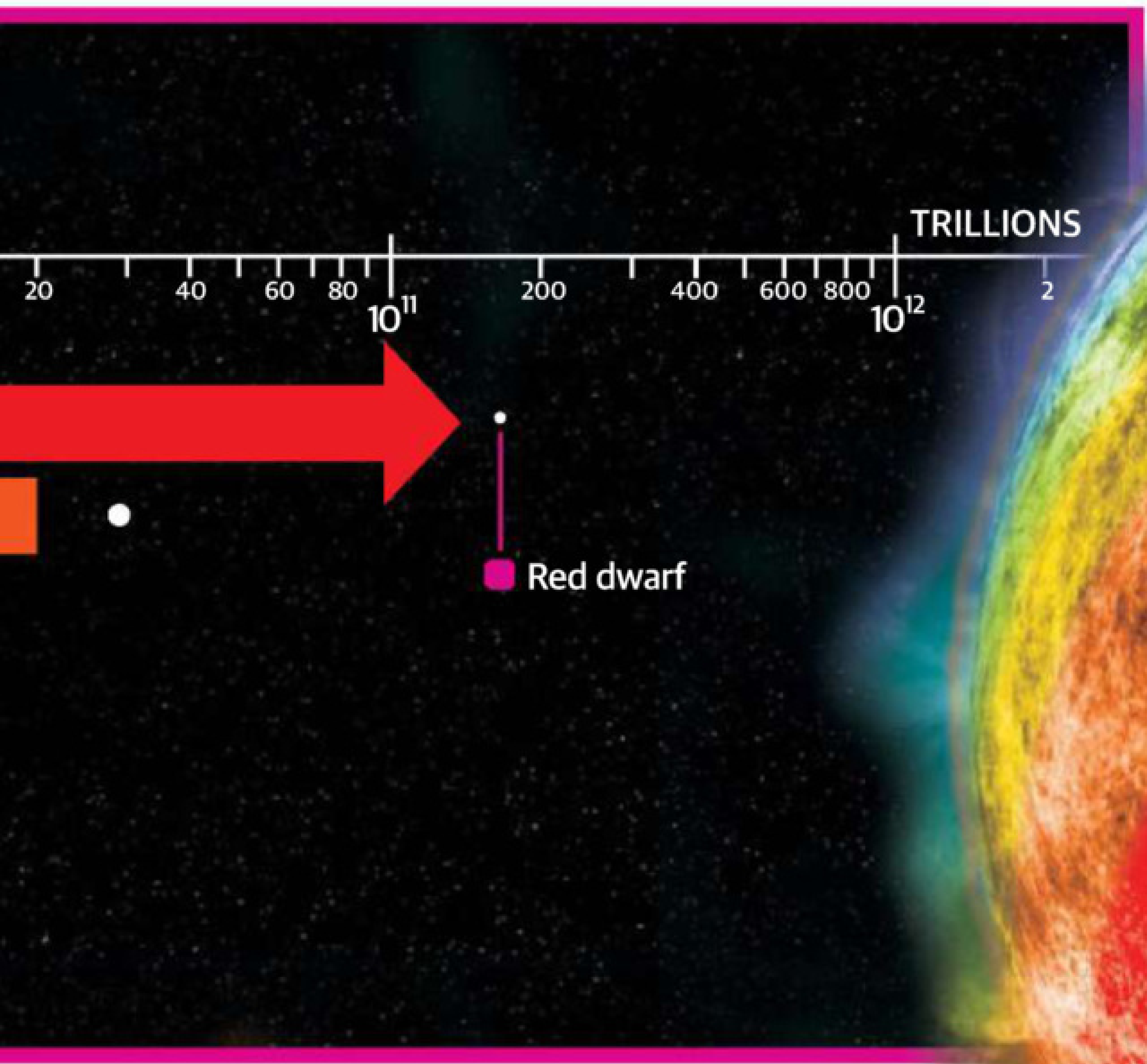


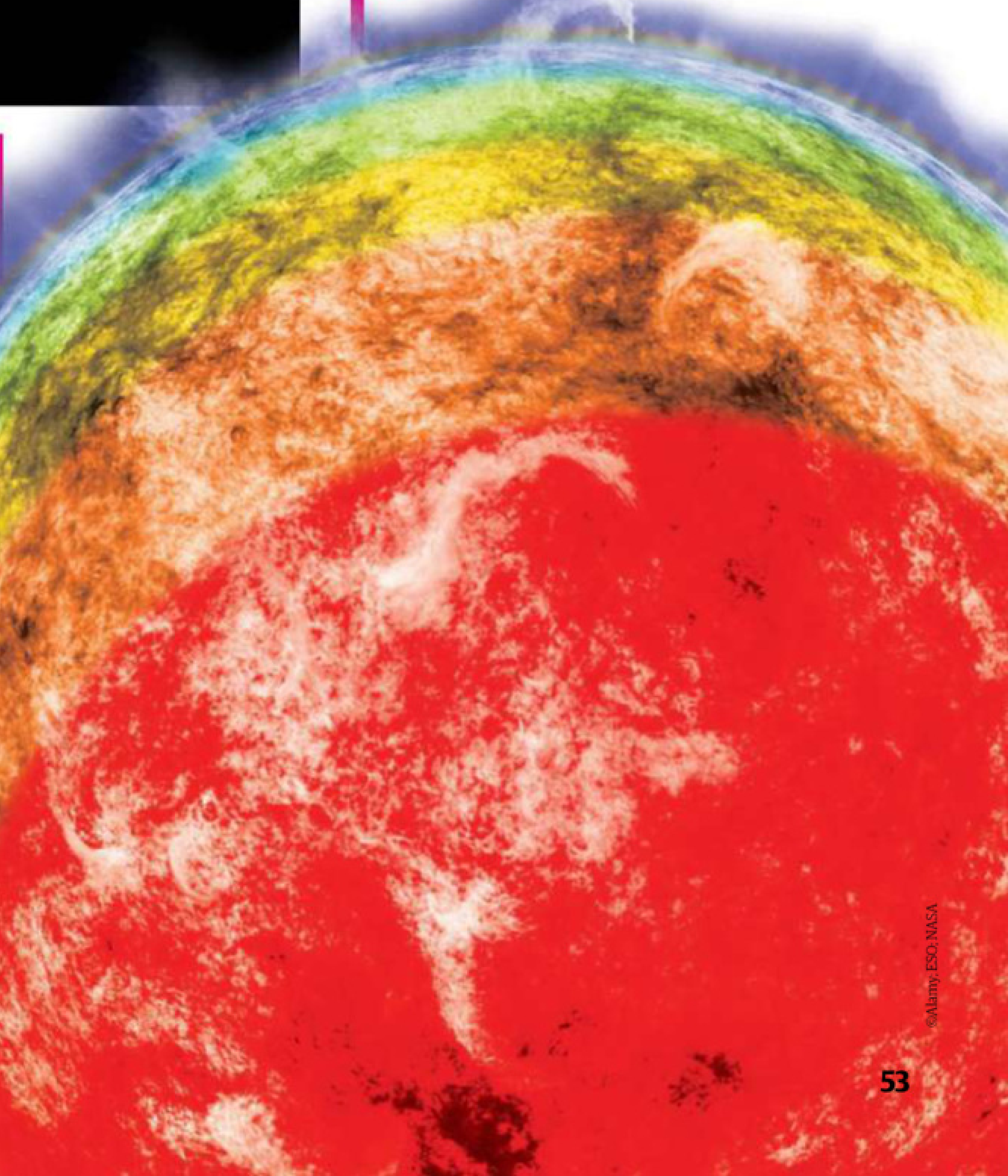
OGLE-TR-122b (centre) is the smallest known true star and is pretty much at the extreme bottom end of the main sequence. It's just 16 per cent bigger than Jupiter (right) and has a mass of about one tenth that of the Sun (left)

How many red dwarfs are there?

Percentage of main-sequence stars in the universe

- ● M (red dwarf) 76.45%
- ● K 12.1%
- ● G (the Sun) 7.6%
- ● F 3%
- ● A 0.6%
- ● B 0.13%
- ● O 0.00003%





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5 AMAZING FACTS ABOUT

Spacewalks

Temperatures fluctuate by up to 500 degrees

While on a spacewalk in Earth orbit the temperature changes from a balmy 120 degrees Celsius (250 degrees Fahrenheit) in sunlight to -160 degrees Celsius (-250 degrees Fahrenheit) in darkness. Spacesuits are normally white to reflect light and heat while in the Sun.

It takes hours to get ready for a spacewalk

For modern spacewalks it takes about 45 minutes to don the 125-kilogram (280-pound) suit. The astronauts must then spend an hour pre-breathing pure oxygen to adapt to the lower-pressure environment maintained in the suit before heading out of the airlock.

The first spacewalk almost ended in disaster

During humanity's first spacewalk, performed by Soviet Alexei Leonov on the Voskhod 2 mission on 18 March 1965, his suit expanded much more than had been expected and he had to leak air from his suit into space in order to get back into the spacecraft.

The longest spacewalk lasted nearly nine hours

NASA astronauts Susan Helms and Jim Voss hold the record for the longest spacewalk in history, set during the ISS Expedition 2 mission when they were outside in the vacuum of space for eight hours and 56 minutes on 11 March 2001.

There has only ever been one three-person spacewalk

The only time three people have simultaneously exited a spacecraft to perform a spacewalk was during Space Shuttle Endeavour's STS-49 mission in May 1992. During the mission Americans Pierre Thuot, Richard Hieb and Thomas Akers captured the Intelsat VI satellite.

The STS-49 mission crew during their spacewalk

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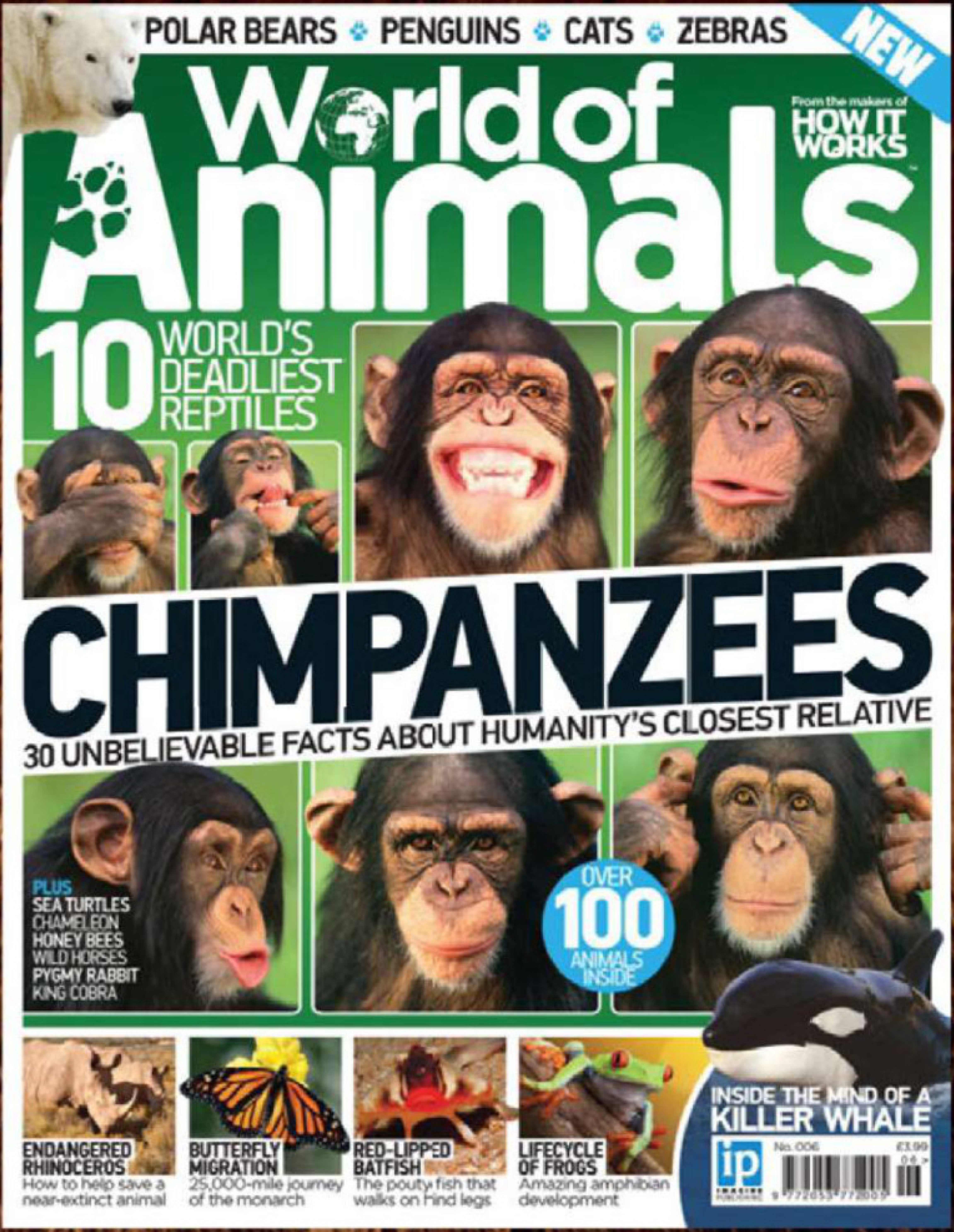

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Supersonic wind tunnels

The science behind the amazing structures that have helped us reach the Moon and beyond

When humans first attempted to take to the skies, we quickly discovered that there was an awful lot to learn about the forces acting on our flying machines. The essential problems of drag and air resistance completely escaped most airborne designs until the arrival of the wind tunnel.

It's generally accepted that Frank H. Wenham was the creative force behind the first wind tunnel back in 1871. He designed a steam-powered fan that blew air down a 3.7-metre (12-foot) horizontal tube, which helped aeronauts learn a lot about drag and lift.

The concept of the wind tunnel was born and there were many improvements made to it over the years, most notably by the Wright brothers, until NASA got involved and took things up a few notches.

NASA has a huge number of wind tunnels, ranging from a few square centimetres to over 365 metres (1,200 feet) long. A supersonic wind tunnel attempts to discover how aircraft and spacecraft cope in real-life situations, as well as test individual supersonic components such as nozzles and inlets.

Modern wind tunnels use a cyclical design, pushing air through a series of tubes, powered by liquid jet fuel, gaseous hydrogen, gaseous oxygen, 40,000-horsepower electric motors and compressors. These are narrow sections of pipes that squeeze the air into a much smaller space, increasing the pressure and speeding up the airflow. The airspeed can be carefully monitored and changed by altering the power output of the motors and slightly widening or narrowing the width of the compressors. The compressor walls can be changed by a mere five-thousandth of an inch in order to create the exact wind speed. The data then gets carefully scrutinised by an on-site team of scientists, before being made available for the public to look at.

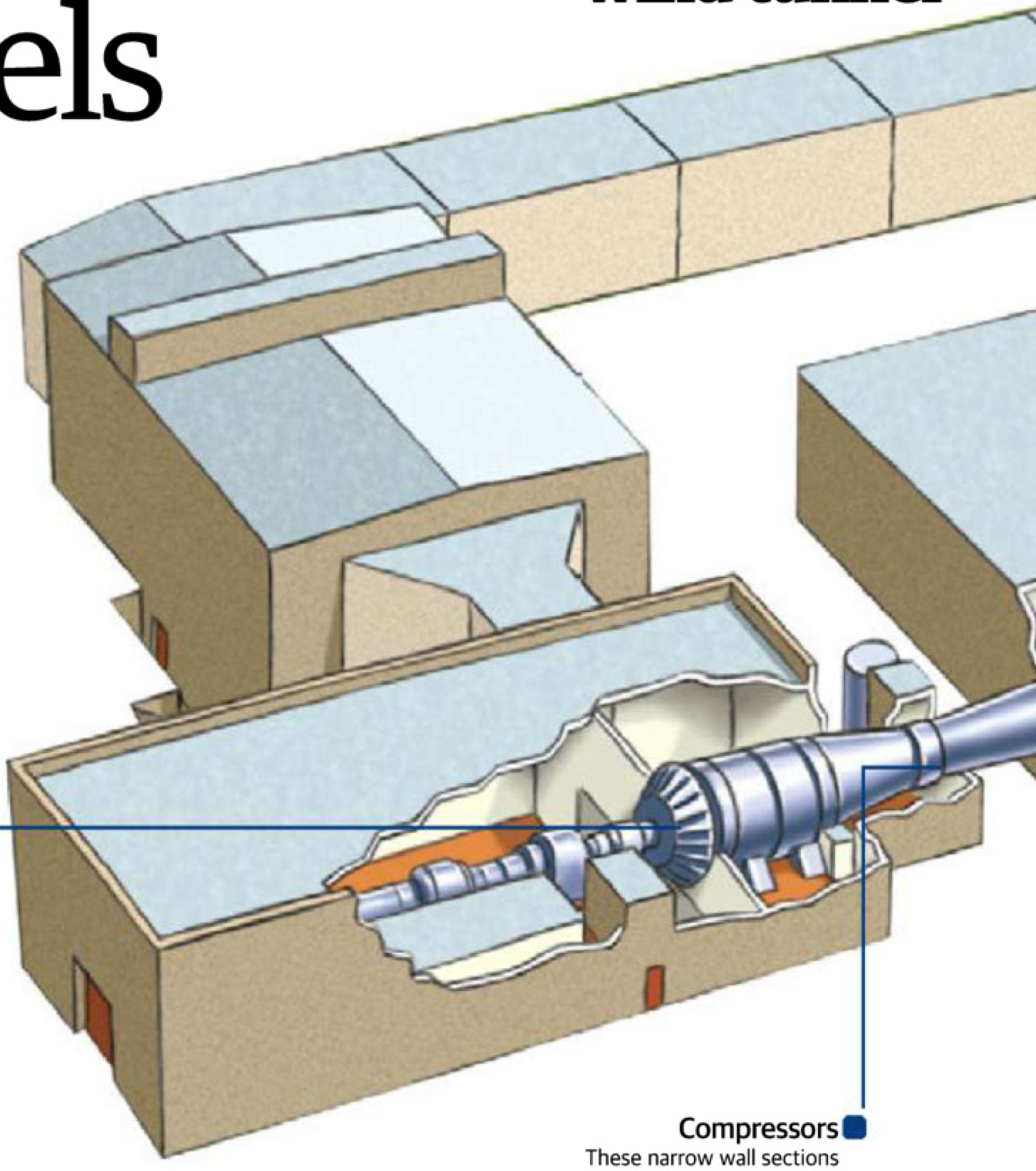
There are two main types of wind tunnel test. First a closed-loop test that circulates air through the system over a long period of time, recycled by returning the air to the powered fan that blows it back down the tube. The other common type of test is the open-loop system, where the air is highly pressurised and only powers through the system a few times before being released. While in the tunnel, aircraft, spacecraft or models are either turned on and operated to accurately simulate flight, or held in place by a strong magnetic field.

The Abe Silverstein Supersonic Wind Tunnel at the NASA Glenn Research Center was built in 1956. This facility can send air around the system at speeds of up to Mach 3.5, putting aircraft and their components under immense pressure, so engineers can discover how it would cope under that level of strain.

> "Apollo 11's command module was tested in a number of wind tunnels, each exerting a different force on it"

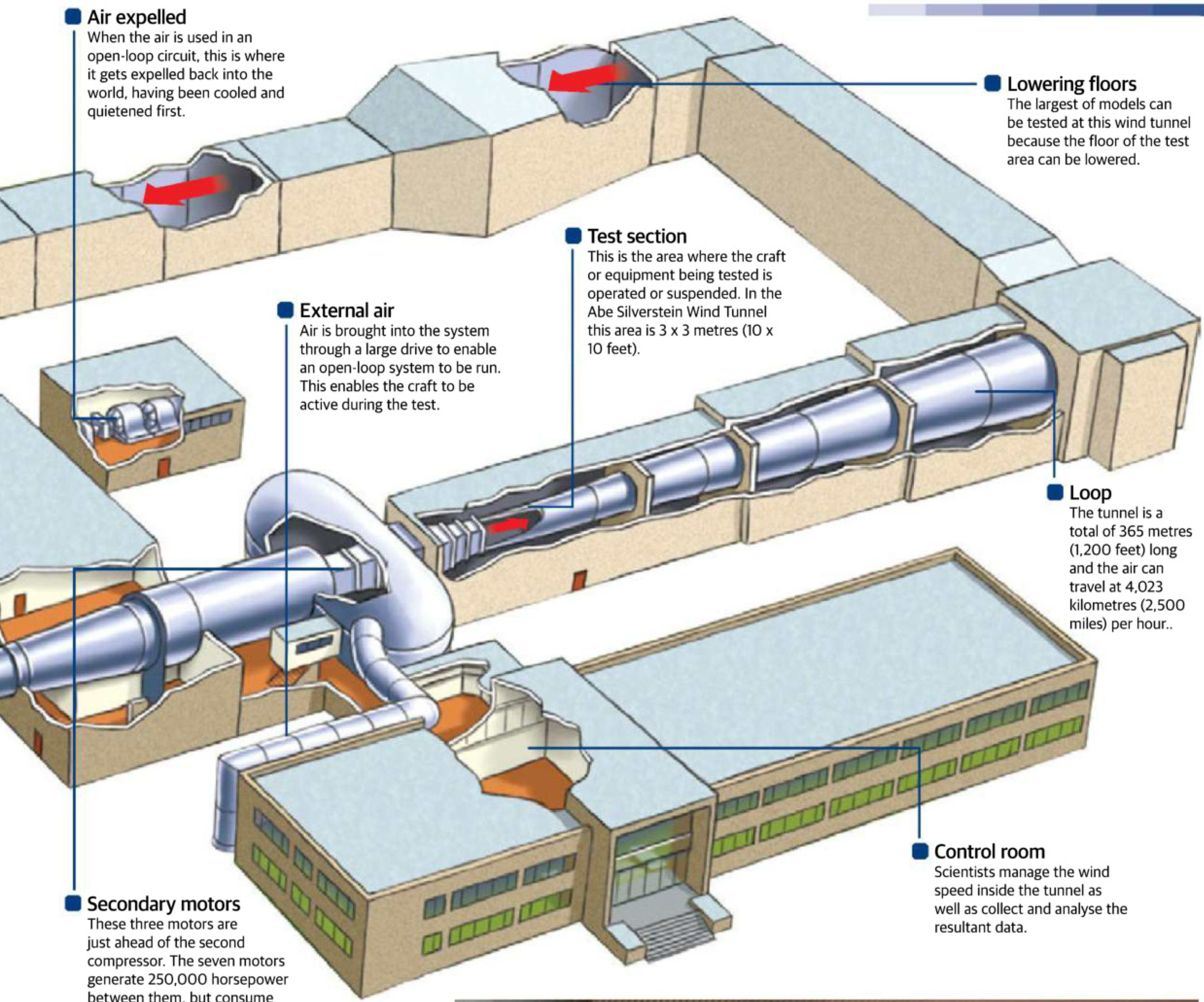
Its smaller cousin, the Supersonic Wind Tunnel, is able to help engineers closely investigate the effects of switching between Mach 0.8 and 1.2, where the craft edges either side of the sound barrier. These wind tunnels helped many famous space projects get off the ground, such as the famous Apollo missions. For example, tests were conducted in NASA wind tunnels at Mach 0.4 to 19 to discover what kind of pressure would be exerted on the command module as it left Earth's atmosphere. Apollo 11's command module was tested in a number of different wind tunnels, each exerting a different force on it. The data drawn from these tests was key in the success of the mission to the Moon.

Inside NASA's Glenn Research Center wind tunnel



Main motors
The electric motors generate 40,000 horsepower and four are positioned just ahead of the main compressor to regulate the speed of the air flowing into them.

Compressors
These narrow wall sections vastly increase the air pressure, causing the air to accelerate. They're moved by hydraulic jacks by as little as five-thousandth of an inch.



Air expelled
When the air is used in an open-loop circuit, this is where it gets expelled back into the world, having been cooled and quietened first.

Lowering floors
The largest of models can be tested at this wind tunnel because the floor of the test area can be lowered.

Test section
This is the area where the craft or equipment being tested is operated or suspended. In the Abe Silverstein Wind Tunnel this area is 3 x 3 metres (10 x 10 feet).

External air
Air is brought into the system through a large drive to enable an open-loop system to be run. This enables the craft to be active during the test.

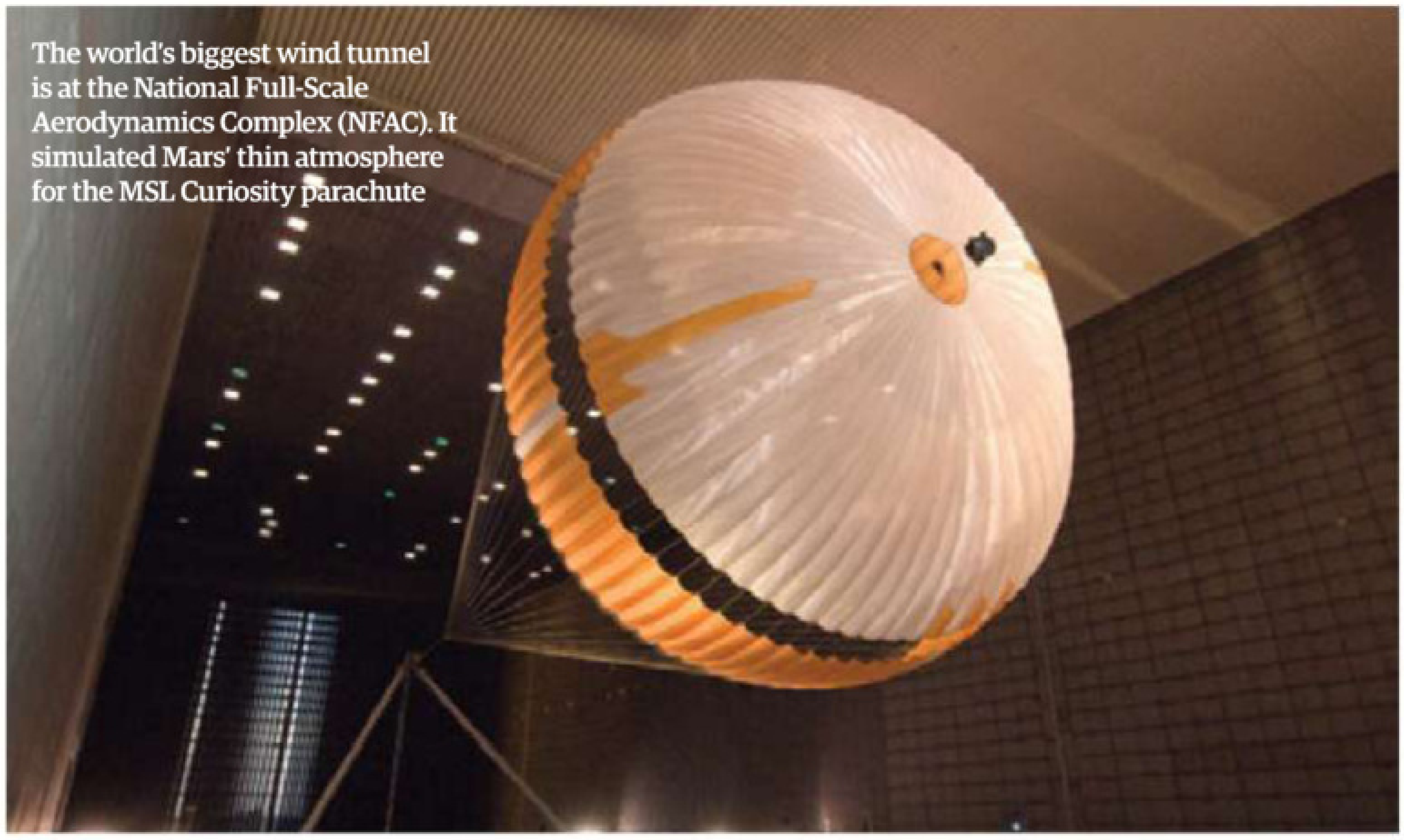
Loop
The tunnel is a total of 365 metres (1,200 feet) long and the air can travel at 4,023 kilometres (2,500 miles) per hour..

Control room
Scientists manage the wind speed inside the tunnel as well as collect and analyse the resultant data.

Secondary motors
These three motors are just ahead of the second compressor. The seven motors generate 250,000 horsepower between them, but consume up to 200 million Watts of electricity per hour.

Modern missions like Orion have also been tested in wind tunnels at NASA to determine how they would cope with returning through the Earth's atmosphere. Here, temperatures inside wind tunnels can reach 1,140 degrees Rankine.

The future of wind tunnels looks like being one of subtle improvements. One of the hardest areas to perfect is Computational Fluid Dynamics (CFD) calculations, which determine how fluids, such as Earth's atmosphere, flow over objects. Current models of calculating CFD need updating, so the next step for NASA is to be able to accurately measure this phenomenon to better understand an aircraft's passage through the atmosphere. ●



The world's biggest wind tunnel is at the National Full-Scale Aerodynamics Complex (NFAC). It simulated Mars' thin atmosphere for the MSL Curiosity parachute

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All About… KEPLER-64

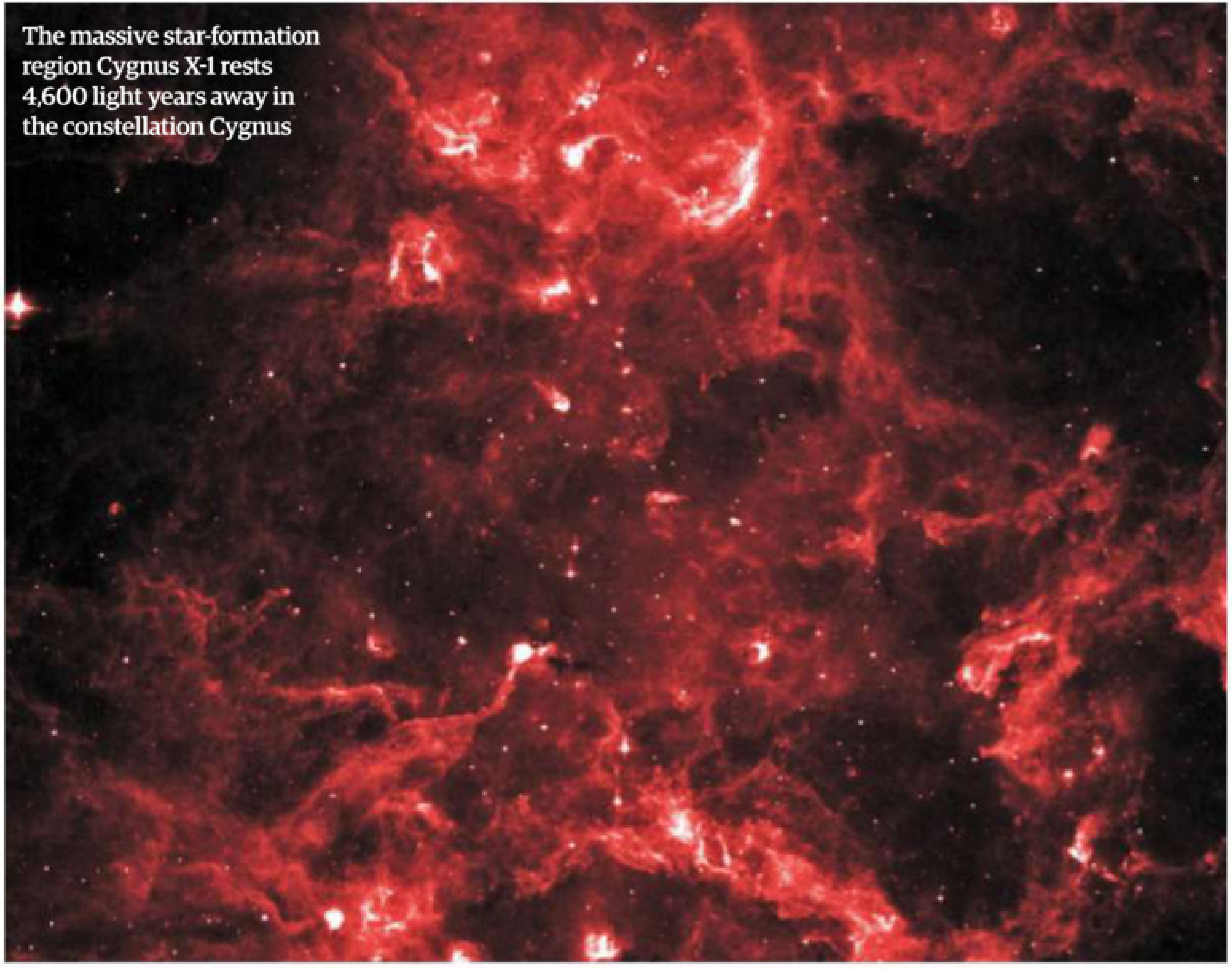
Kepler-64 is a star system of firsts, the greatest of which is the result of work by amateur astronomers, not professionals

Written by Shanna Freeman

Located in the Cygnus constellation in the Milky Way, Kepler-64 is one of the most visible star systems in the sky and known for containing the asterism, or star pattern, called the Northern Cross. Cygnus is very large, covering about 804 square degrees and nearly two per cent of the night sky.

Kepler-64 also keeps some interesting company: the brightest star in the constellation, Deneb (or Alpha Cygni), is a white giant and one of the most luminous detected. Cygnus also contains numerous X-ray sources, including the black hole candidate Cygnus X-1, the binary star pair Cygnus X-2 and the microquasar Cygnus X-3. Cygnus A was the first radio galaxy to be discovered and one of the strongest sources of radio waves in the sky. These galaxies have extremely luminous radio wavelengths. The constellation also contains a massive star formation region, known as Cygnus X.

> "About a hundred stars in the Cygnus constellation have planets in orbit, [and] more are being discovered all the time"


The massive star-formation region Cygnus X-1 rests 4,600 light years away in the constellation Cygnus

Because the Kepler mission - a NASA space observatory launched to help discover Earth-sized extrasolar planets - had its field of view focused on a region that includes Cygnus, it has become the constellation with the most known planets. About a hundred stars in the constellation have planets in orbit around them, while more are being discovered all the time and confirmed after analysis.

Kepler-64b may be one of as many as 100-400 billion exoplanets in the Milky Way. Astronomers at Caltech conducted a study based on the planets that orbit Kepler-32, a star discovered in January 2012, which posits that there could even be as many planets as stars in our galaxy.

The first star system to have six transiting planets, Kepler-11, was announced on 2 February 2011. It's also one of the flattest and most compact systems - for some context almost all six of the planets would fit inside the orbit of Mercury.

While Kepler-16b, announced later that year in September 2011, was called the Tatooine planet because it was the first found to be orbiting two stars. The stars are an eclipsing pair, similar to those orbited by Kepler-64b. There's also Kepler-69c, a confirmed super-Earth extrasolar planet that's estimated to be about two-thirds larger than Earth. It orbits a Sun-like star and is thought to be terrestrial. Originally the planet was considered to be in the habitable zone, just the right distance from its orbiting star to maintain a temperature capable of supporting liquid water. However, Kepler-69c was later determined to be much more like Venus than Earth. Given that Venus is one of the most inhospitable planets in the Solar System, it doesn't seem likely that anything could survive there.

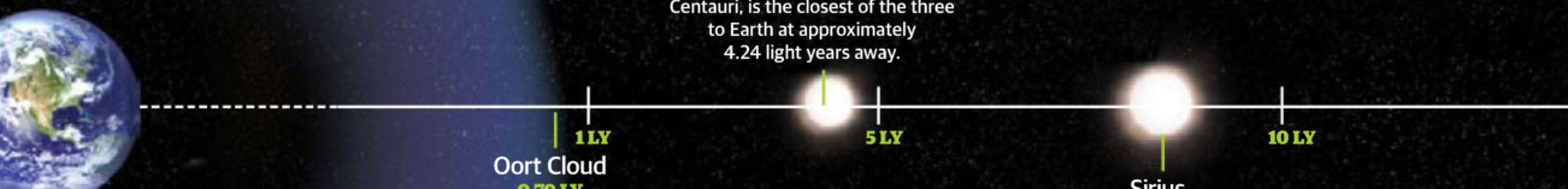
But the discovery of Kepler-64b eclipsed the excitement of Kepler-16b because it too orbits two stars, but also has a binary pair orbiting the initial pair. Kepler-64 is the first quadruple star system with a planet, the first to have a transiting planet and also the first to have a circumbinary (orbiting a binary star system) planet.

Even among over 900 confirmed exoplanets in the Kepler field and over 1,700 exoplanets discovered so far in our galaxy, Kepler-64b is something special. ■

How far is Kepler-64 from us?

1 light year = 63,240 astronomical units

This distant system is a mind-boggling 5,000 light years away from our home planet

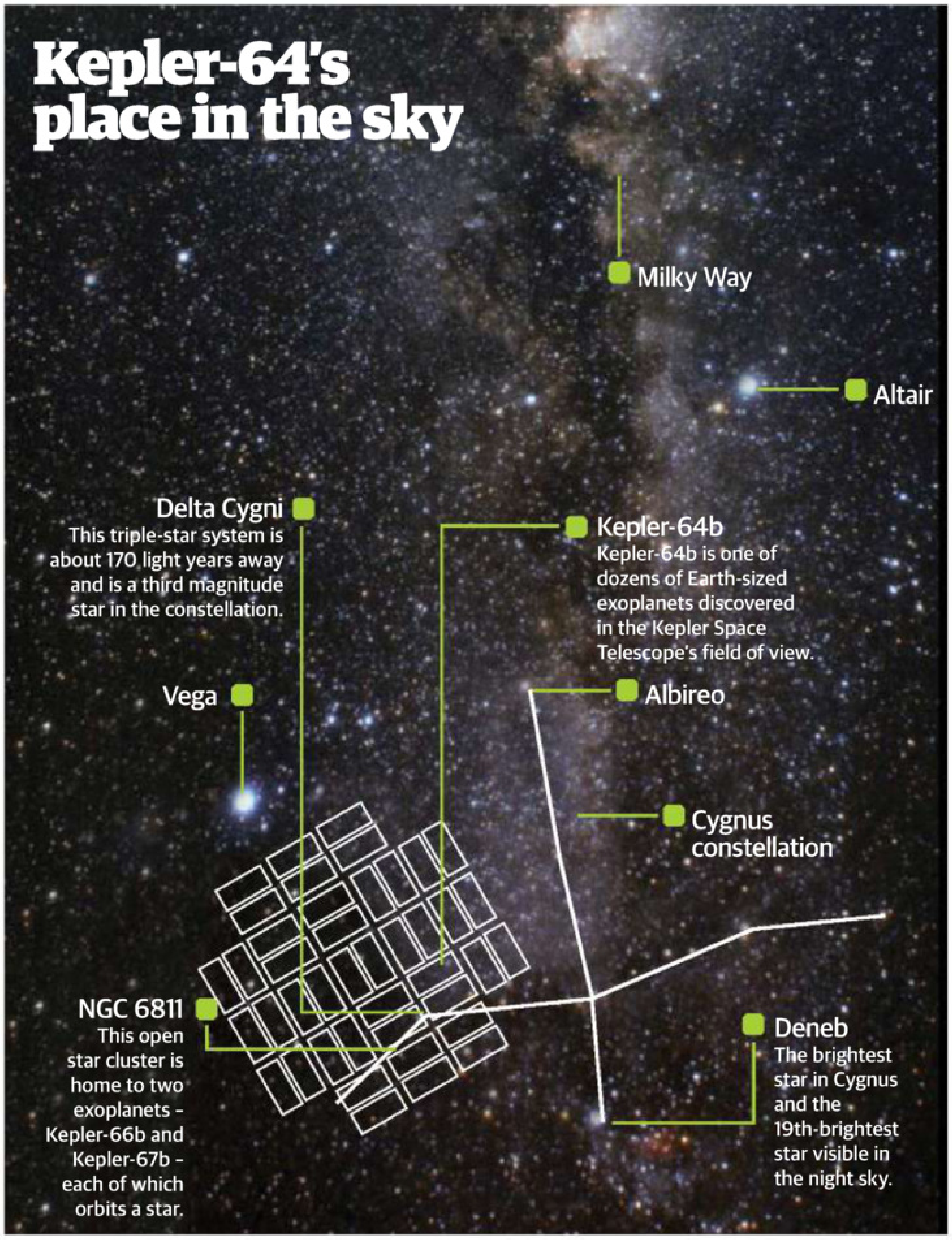


Alpha Centauri
4.37 LY
Actually a system of three stars, the faintest star in the system, Proxima Centauri, is the closest of the three to Earth at approximately 4.24 light years away.

Oort Cloud
0.79 LY
This hypothesised icy cloud is estimated to contain billions of planetesimals and occupy a space somewhere between 2,000 and 50,000AU.

Sirius
8.6 LY
Called the Dog star for its position in the Canis Major constellation, Sirius is the brightest star in our night sky.

Kepler-64's place in the sky



Delta Cygni
This triple-star system is about 170 light years away and is a third magnitude star in the constellation.

Kepler-64b
Kepler-64b is one of dozens of Earth-sized exoplanets discovered in the Kepler Space Telescope's field of view.

NGC 6811
This open star cluster is home to two exoplanets – Kepler-66b and Kepler-67b – each of which orbits a star.

Deneb
The brightest star in Cygnus and the 19th-brightest star visible in the night sky.

By the numbers

961
The number of confirmed planets so far found by the Kepler Space Telescope, but there are many more candidates

20-55
The estimated Earth masses of PH1b

6.2
PH1b has a total radius about 6.2 times Earth's

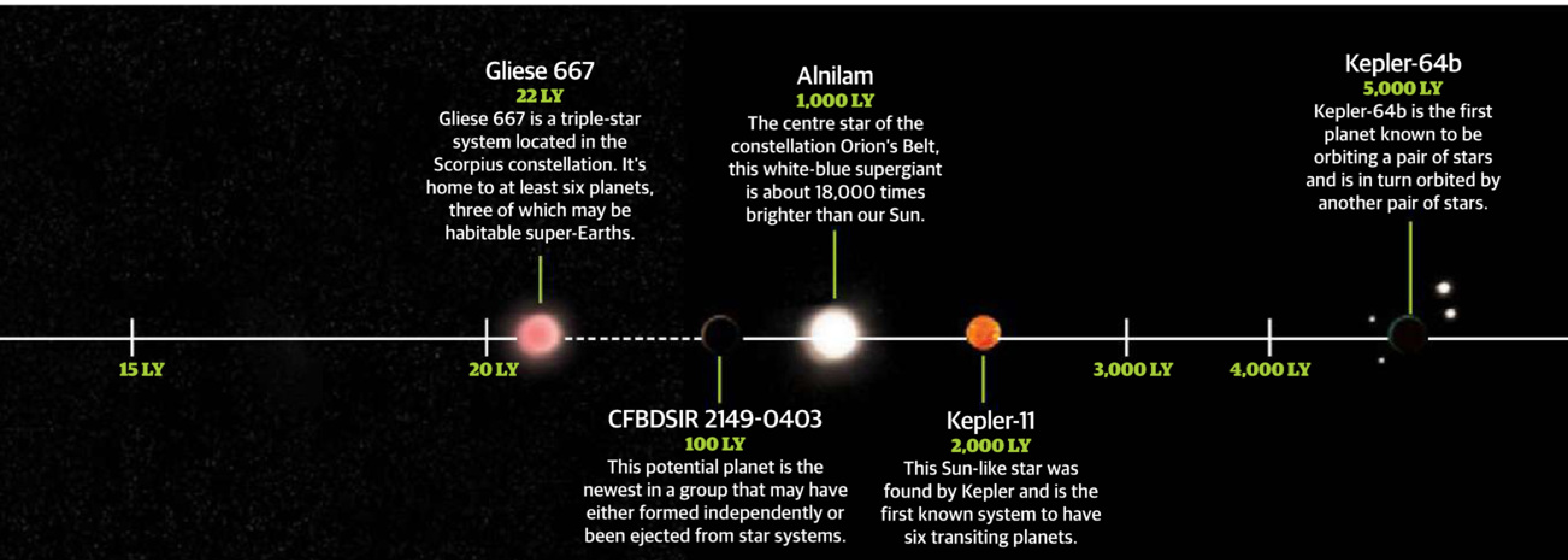
5,000
The number of light years Kepler-64 is from Earth

1,000
The two binary star pairs are 1,000 times farther apart than our Sun and the Earth

6th
PH1b was just the sixth known circumbinary planet

34
Potential planets found via Planet Hunters

21,247,427
The number of Kepler observations analysed by citizen scientists at Planet Hunters



Gliese 667
22 LY
Gliese 667 is a triple-star system located in the Scorpius constellation. It's home to at least six planets, three of which may be habitable super-Earths.

CFBDSIR 2149-0403
100 LY
This potential planet is the newest in a group that may have either formed independently or been ejected from star systems.

Alnilam
1,000 LY
The centre star of the constellation Orion's Belt, this white-blue supergiant is about 18,000 times brighter than our Sun.

Kepler-11
2,000 LY
This Sun-like star was found by Kepler and is the first known system to have six transiting planets.

Kepler-64b
5,000 LY
Kepler-64b is the first planet known to be orbiting a pair of stars and is in turn orbited by another pair of stars.

A look inside Kepler-64

The unique makeup of this quadruple star system sets it apart from even the most impressive of Kepler's discoveries

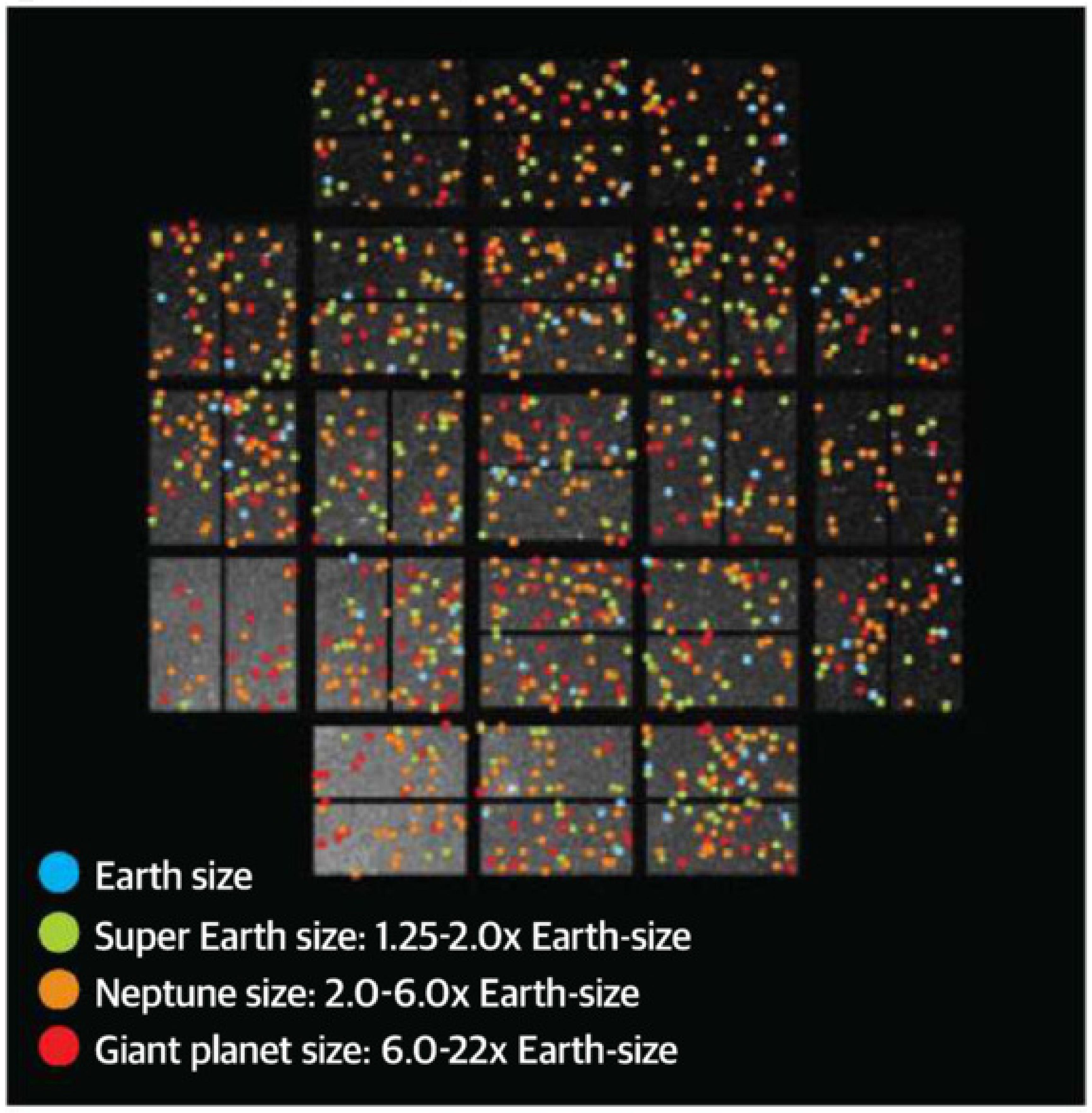
Kepler-64 is a quadruple star system located about 5,000 light years from Earth and estimated to be about 2 billion years old. Also known as KIC 4862625 in the Kepler catalogue, this system comprises two binary stars designated Aa+Ab and Ba+Bb. The planet PH1b, or Kepler-64b, is a circumbinary planet orbiting the Aa+Ab binary. As of 2013 there are less than 20 confirmed circumbinary planets in existence, but information gathered by the Kepler mission indicates that there are probably many more, with a wide range of star and planetary types and sizes.

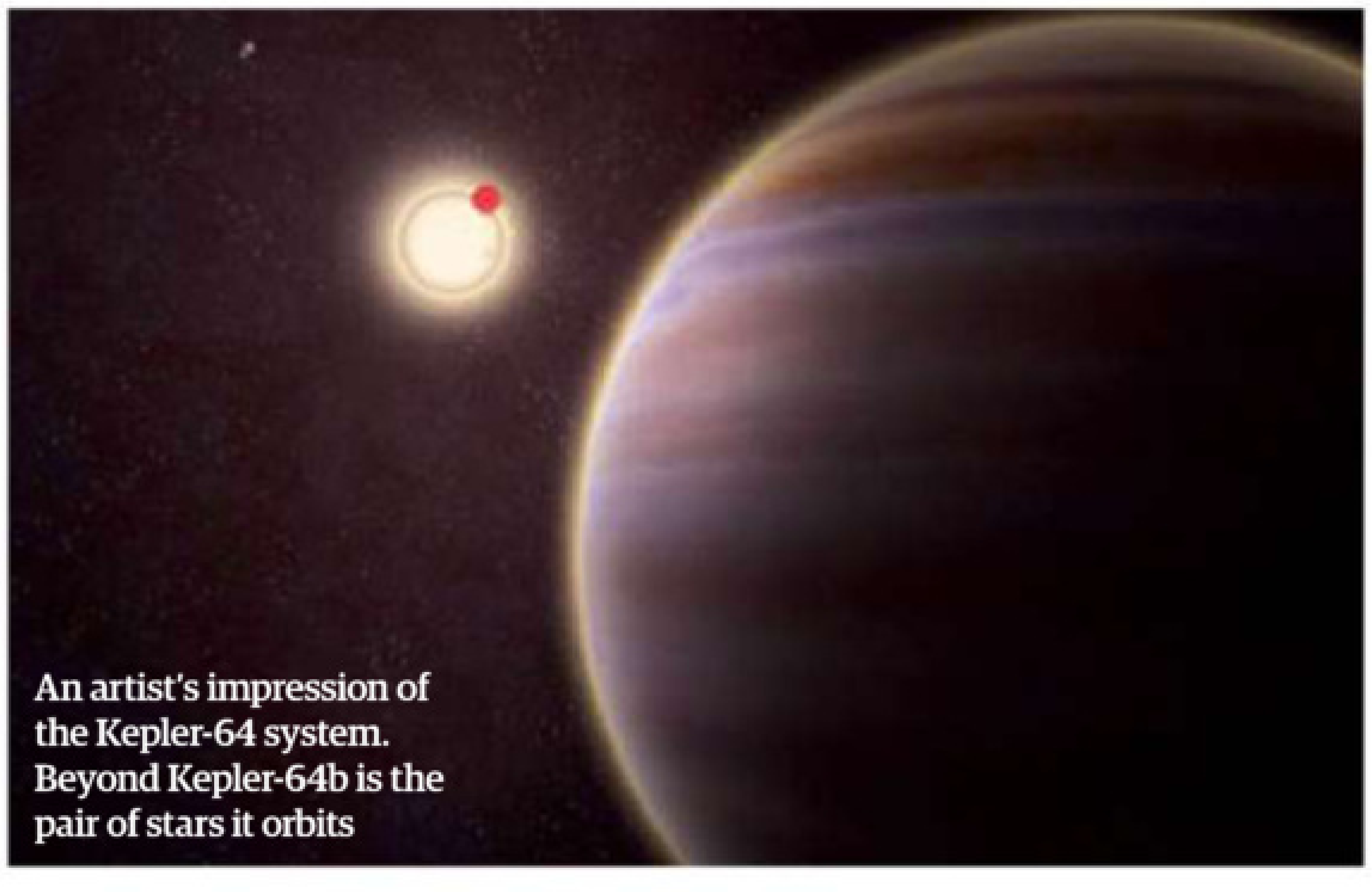
Kepler-64b orbits its binary pair very close to the stars' plane, suggesting that the planet probably formed from a single protoplanetary disc of gases and debris, left over from the formation of the stars. Recent studies of circumbinary planets that orbit close to their stars suggest that they formed in violent ways, as the gravitational pull from the binary star system would have pulled very strongly on the protoplanetary disc.

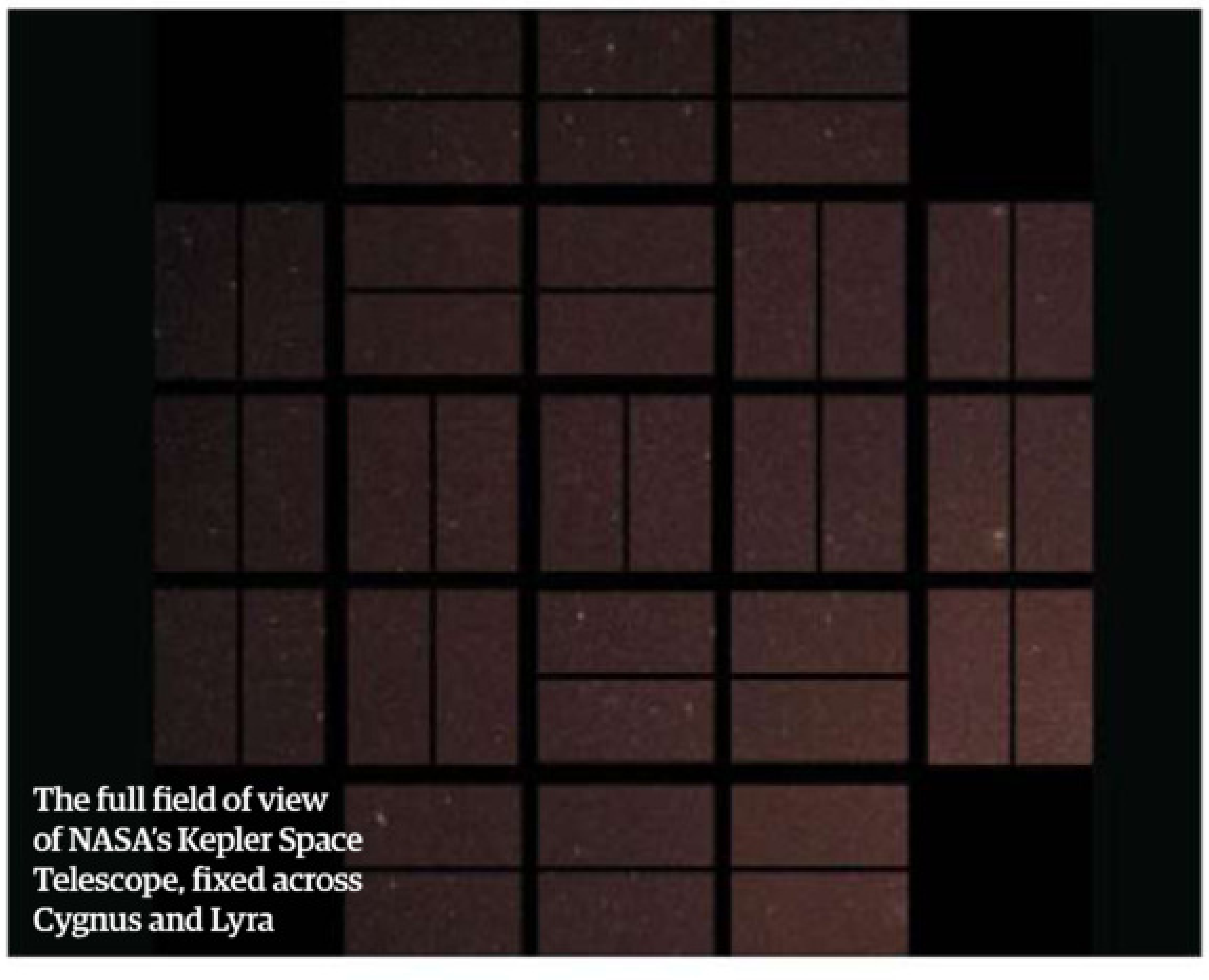
The planet is similar to Neptune and thought to be a gas giant with a diameter six times that of Earth's. All confirmed circumbinary planets have so far been smaller than Jupiter and no terrestrial circumbinary planets have been found. Kepler-64b could have terrestrial moons, but it's so close to the binary stars – ie closer than Venus is to our Sun – that any moon would be far too hot to be habitable for life as we know it.

The primary binary pair of stars are both dwarfs: Aa is the larger and brighter of the two, a yellow F-type with a solar mass of 1.5 and somewhat hotter than our Sun. Kepler Ab is a red M-type dwarf with a solar mass of 0.41. These two stars are also very close together and orbit each other.

After the discovery of PH1b as a candidate exoplanet, additional observations were needed for confirmation. At the time it was thought to just be part of a binary star system, but spectroscopic observations from the Keck Telescope in Hawaii not only confirmed the planet but also revealed a secondary pair of stars orbiting far from the primary pair. The secondary pair of stars is located about 1,000AU from the first, orbiting each other. Ba is a G-type dwarf (the same class as our Sun), with a solar mass of 0.99, while Bb is an M-type dwarf with a solar mass of 0.51.




An artist's impression of the Kepler-64 system. Beyond Kepler-64b is the pair of stars it orbits


The full field of view of NASA's Kepler Space Telescope, fixed across Cygnus and Lyra

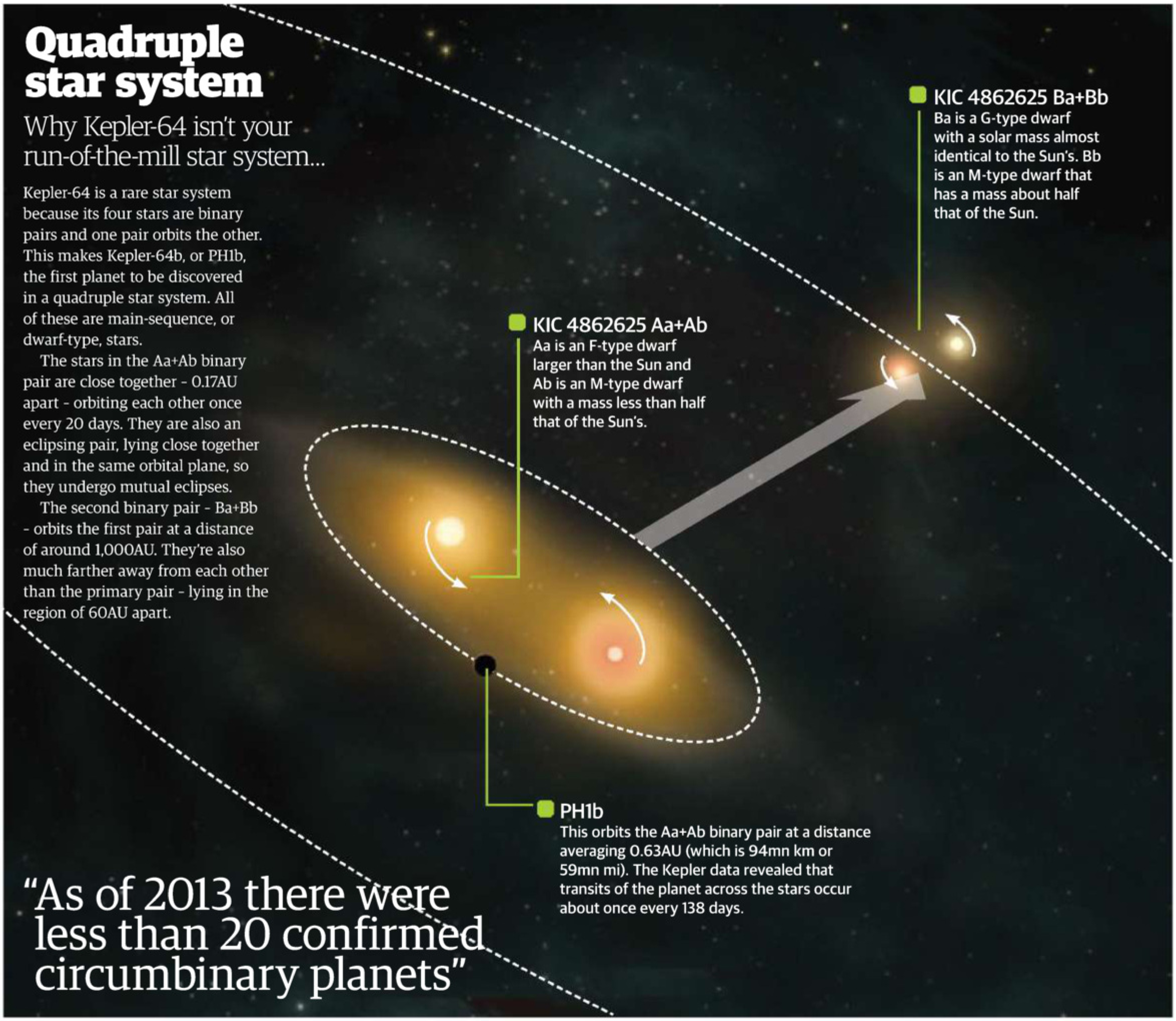
Quadruple star system

Why Kepler-64 isn't your run-of-the-mill star system...

Kepler-64 is a rare star system because its four stars are binary pairs and one pair orbits the other. This makes Kepler-64b, or PH1b, the first planet to be discovered in a quadruple star system. All of these are main-sequence, or dwarf-type, stars.

The stars in the Aa+Ab binary pair are close together - 0.17AU apart - orbiting each other once every 20 days. They are also an eclipsing pair, lying close together and in the same orbital plane, so they undergo mutual eclipses.

The second binary pair - Ba+Bb - orbits the first pair at a distance of around 1,000AU. They're also much farther away from each other than the primary pair - lying in the region of 60AU apart.



KIC 4862625 Ba+Bb
Ba is a G-type dwarf with a solar mass almost identical to the Sun's. Bb is an M-type dwarf that has a mass about half that of the Sun.

KIC 4862625 Aa+Ab
Aa is an F-type dwarf larger than the Sun and Ab is an M-type dwarf with a mass less than half that of the Sun's.

PH1b
This orbits the Aa+Ab binary pair at a distance averaging 0.63AU (which is 94mn km or 59mn mi). The Kepler data revealed that transits of the planet across the stars occur about once every 138 days.

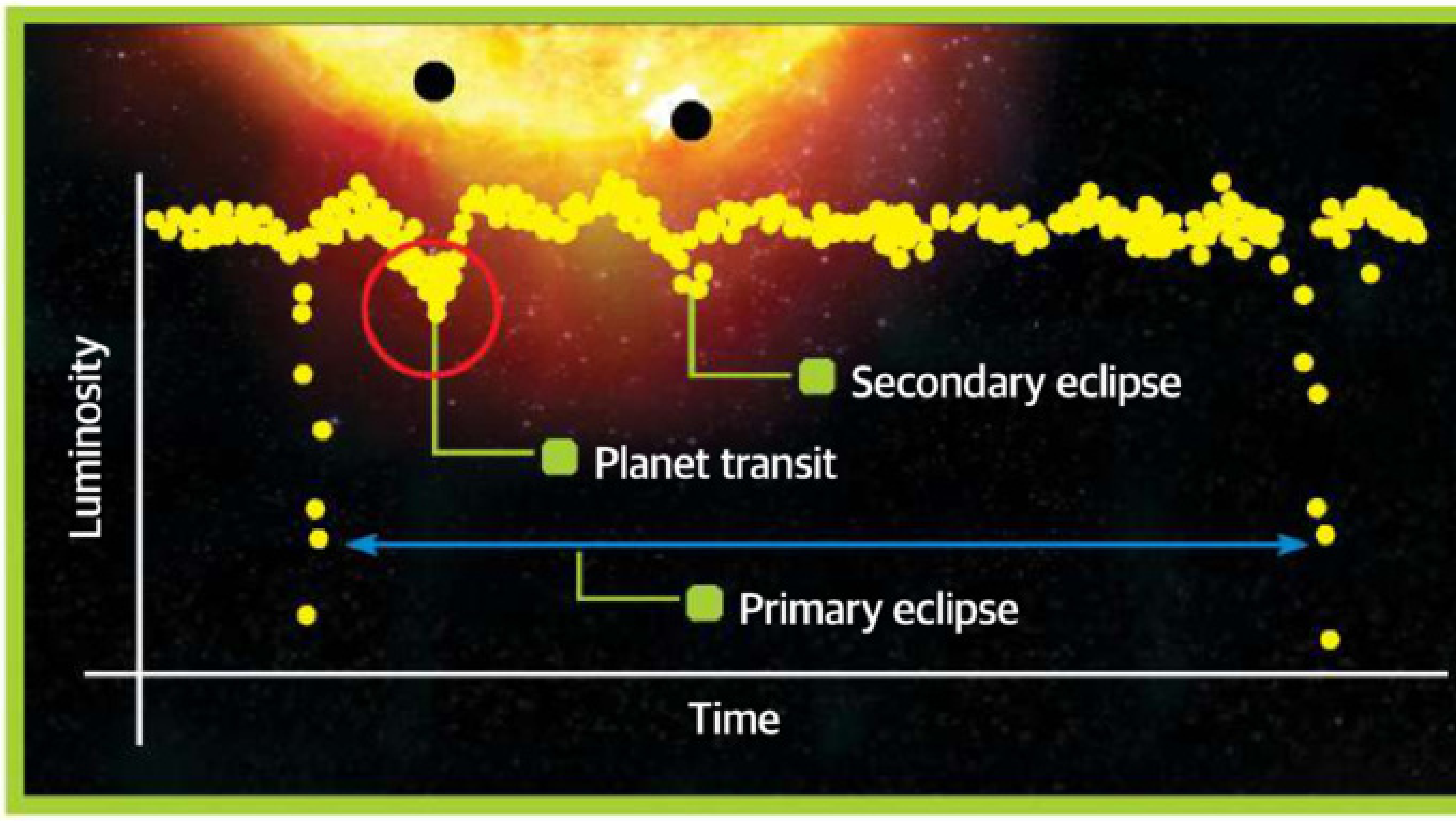
> "As of 2013 there were less than 20 confirmed circumbinary planets"

Finding an exoplanet

Kepler-64b was discovered using the transit method. If a terrestrial planet is orbiting a star, it will cause small fluctuations in its brightness as it transits (ie passes in front of) the light. Stars can fluctuate in brightness by themselves, but if the changes are caused by a transiting planet, a distinct pattern will emerge.

These transits will last a certain length of time, usually between two and 16 hours, and the brightness will fluctuate by the same amount each time. The amount depends on the relative sizes of the stars and the planet and by examining these patterns - which appear as periodic dips in a histogram - we can find exoplanets, as well as estimate their orbital length, size and mass.

This method can result in a high rate of false positives, which is why they're called potential exoplanets until their existence can be confirmed using other planetary detection methods.



The Kepler Telescope

How the wealth of data from this technological first is still fuelling experts and amateurs alike in their hunt for exoplanets

Kepler-64b is just one of the nearly 4,000 candidate exoplanets (with close to 1,000 confirmations) discovered using the Kepler Space Telescope. Kepler points to Cygnus (along with parts of Draco and Lyra) because it's out of the ecliptic plane, so light can't reach its photometer.

The tenth in NASA's Discovery programme, Kepler was designed to be a highly focused and lower-cost mission to explore and add to our understanding of the Solar System. The observatory was launched by NASA on 6 March 2009, charged with fixating on a specific portion of the sky to find extrasolar Earth-sized planets in the habitable zone. It was also designed to determine the number of stars in the Milky Way that have these types of planets.

Its field of view includes more than 100,000 stars, which it simultaneously monitors. The spacecraft itself is simple, with one main instrument: a photometer that measures the brightness of the stars, before sending the data back to Earth for analysis of the transit patterns.

At the time of its launch Kepler had the largest camera ever sent into space (with a total resolution of 95 megapixels), the largest mirror to be sent outside Earth orbit (1.4 metres/4.6 feet in diameter) and the fastest download speeds. It sent back its first science data on 19 June 2009 and in January of the following year the team announced that it had discovered five new exoplanet candidates.

After that, discoveries from Kepler were announced in fairly quick succession. New exoplanet candidates were not only discovered and confirmed, but the number, size and orbital periods of Earth-like planets in general could be inferred from the data. In December 2011, the first Earth-sized exoplanets, Kepler-20e and Kepler-20f, were announced. The mission was going well – until it hit a snag.

Although it was intended to last until at least 2016, the Kepler spacecraft began experiencing problems in July 2012. The space observatory has four reaction wheels – gyroscopic devices used for attitude control, or pointing. One of the wheels wasn't working correctly, which prevented the spacecraft from pointing with enough accuracy at its field of view to record data. After a second wheel failed, Kepler was put in a rest state to conserve fuel. In August 2013, NASA announced that the two reaction wheels could not be repaired and the original mission was at an end. The space agency began soliciting other ways to keep using the craft.

The first mission may have ended, but Kepler sent back so much data that more exoplanets are still being discovered all the time. For example, the discovery of Kepler-64b was announced after the spacecraft had stopped collecting data. Because there is so much data, scientists at Yale University launched an initiative called Planet Hunters. Part of the Zooniverse project – a citizen science web portal in which anyone can perform research – Planet Hunters enlists volunteers to view data collected by Kepler in the form of graphs. Terming its participants citizen scientists, the Planet Hunters initiative operates under the idea that people are better than computers at identifying the transit patterns. In fact, it was two citizen scientists who worked together via a forum run by Planet Hunters to spot the dips and confirm the transits that indicated the existence of Kepler-64b.

> "Planet Hunters enlists volunteers to view data collected by Kepler in the form of graphs"

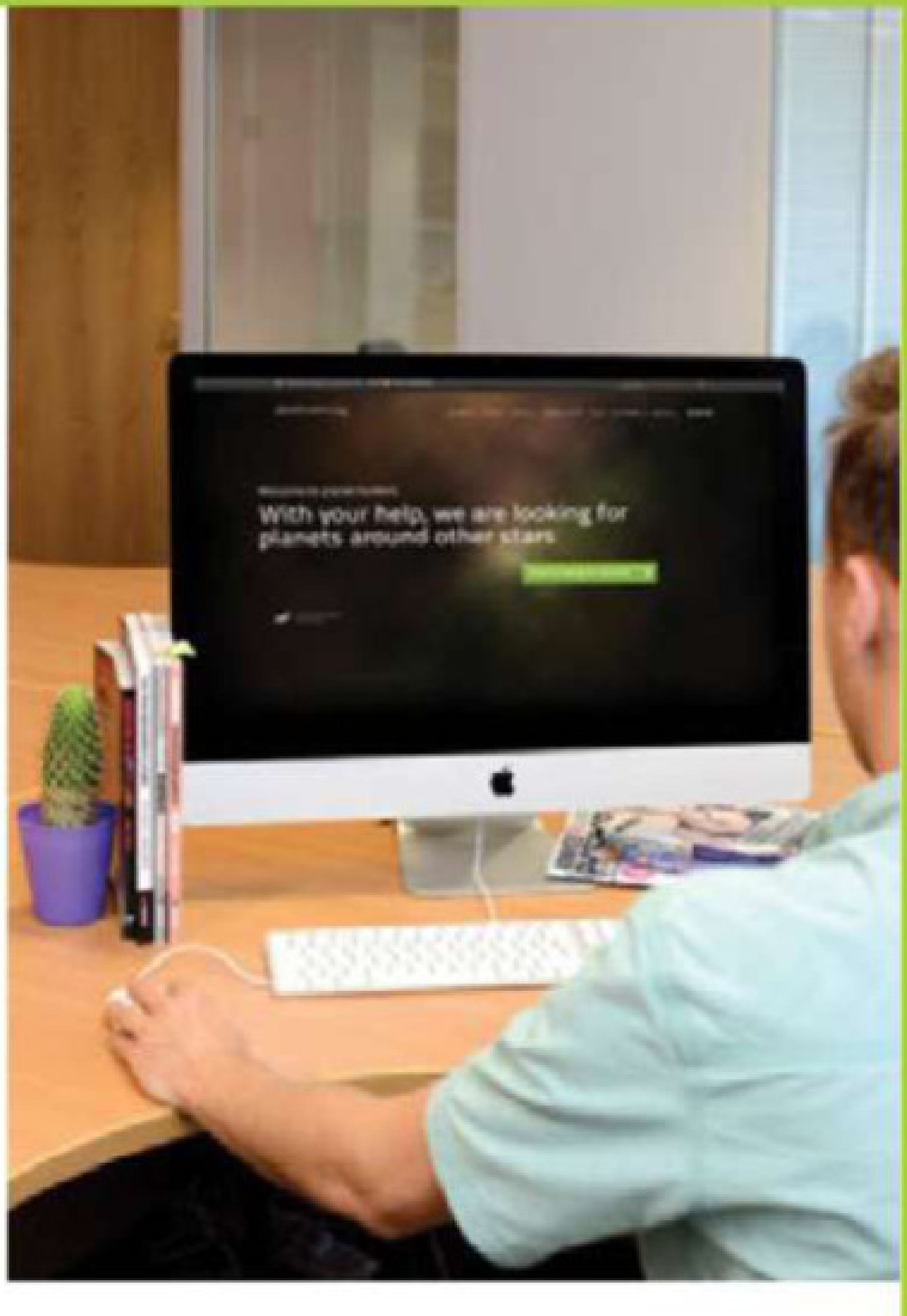
The Kepler Space Telescope beginning its third stage of development in 2009

Join the hunt for exoplanets

You too can help find new planets from the comfort of your own home. More than 20 million observations from Kepler have been analysed and 34 potential planets discovered.

Once you sign up, you'll go through a short tutorial that explains how to determine light curves, variables or quiet (stable). Then you can just look for dips in the curve that might indicate a transiting planet. If multiple citizen scientists report potential transits that haven't already been identified as potential planets, the science team uses the Keck Telescope in Hawaii to gather more data.

If confirmed, users who spotted the transits get acknowledgement for their find. As Kepler-64b (or PH1b) was the first confirmed planet discovered using the initiative, the names of the citizen scientists – Kian Jek and Robert Gagliano – have been widely reported in the media. They are listed as co-authors of a paper submitted to *The Astrophysical Journal.*


With your help, we are looking for planets around other stars

Second chance for Kepler

How photons from the Sun could help set the craft back on course

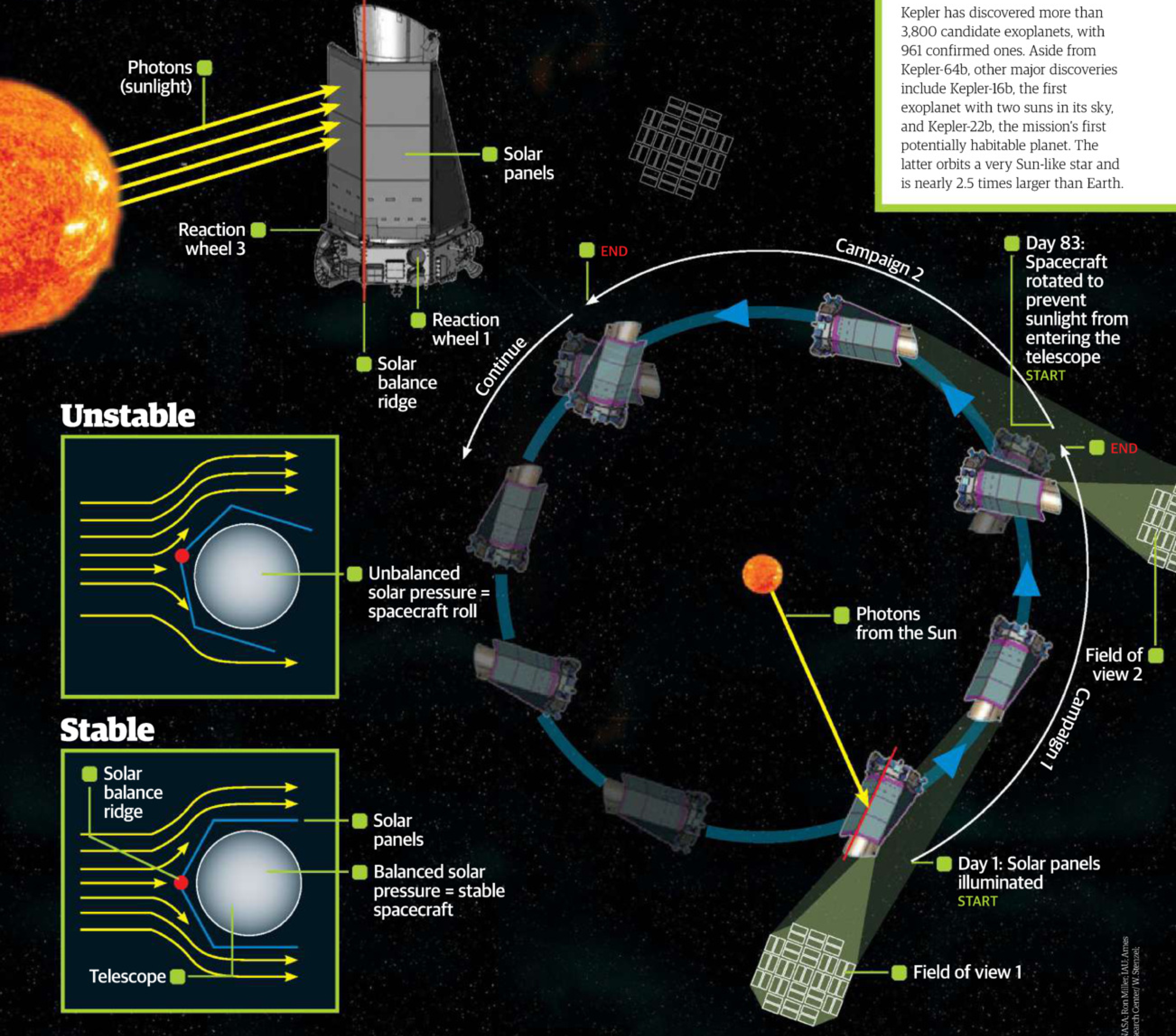
In order to point the Kepler Space Telescope precisely enough to detect Earth-sized exoplanets, it needed at least three of its reaction wheels to function properly. When repair attempts were unsuccessful, it seemed that Kepler's mission was at an end. However, a creative plan for fixing the telescope was presented at NASA's 2014 Senior Review and a decision is expected this summer about the future of the mission. Called K2, or Second Light, the mission would use the telescope's remaining capabilities to continue searching for exoplanets, as well as looking for supernovas and other bodies in the Solar System. The plan is to use the solar pressure - the very force that the wheels were initially counteracting - as a sort of third wheel to reposition the craft. Final mission details are still being worked out, but operational tests so far have been successful.

Mission profile

Kepler Second Light

Original launch: 6 March 2009
Original failure date: 11 May 2013
New mission date: Decision due in summer 2014
Instrument mass: 1,052kg (2,319lb)

Kepler has discovered more than 3,800 candidate exoplanets, with 961 confirmed ones. Aside from Kepler-64b, other major discoveries include Kepler-16b, the first exoplanet with two suns in its sky, and Kepler-22b, the mission's first potentially habitable planet. The latter orbits a very Sun-like star and is nearly 2.5 times larger than Earth.



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Big Bang: not just a theory

It's the biggest announcement in science since the Higgs Boson: All About Space talks to one of the founders of the project that has just confirmed the Big Bang theory of cosmic inflation

Interviewed by Ben Biggs

INTERVIEWBIO

Prof James Bock

Professor Bock is co-leader of BICEP and, as one of the founders, has been with the project since its inception in 2001 over a game of tennis with astrophysicist Professor Brian Keating. He has worked as a researcher at NASA's Jet Propulsion Lab and specialises in experimental cosmology at the prestigious California Institute of Technology (Caltech).

The Dark Sector Laboratory is home to the BICEP2 telescope (left) and South Pole Telescope (right)

> "It gave a factor of ten improvement in how quickly we could make these measurements... BICEP2 was in the field for three years, so if we had kept going with BICEP1 it would have taken 30!"

Could you tell us a bit about the BICEP2 project? What exactly was it you originally set out to do? How did it differ from the original experiment, BICEP, that it followed?

BICEP2 is a step in a larger programme. We originally started an experiment back in 2001 called BICEP, which was designed to go after this polarisation signal exclusively. The idea emerged from my talking with a post-doc in the group, thinking that this would be an interesting signal to go after. The original BICEP experiment was this small, custom-designed telescope with an angular resolution of about half a degree – a similar size to the full Moon and enough sensitivity to resolve the expected structures. It was really a specialised experiment with a lot of light-gathering power, which meant that, in spite of the small telescope diameter, it had an enormous field of view. The focal point of the telescope is just packed with detectors to give it maximum sensitivity.

Is that what distinguished the BICEP instruments?

With BICEP1 we thought that was a very novel approach, as it hadn't been done before. I was also working on the next generation of detectors – futuristic devices that didn't exist at the time, called antenna-coupled bolometers. We designed the experiment so that we could put in these detectors when they were ready, but we used somewhat old-fashioned detectors.

BICEP1 got out into the field in Antarctica and observed for three years, but it didn't have the sensitivity to detect the signal that we're recording now. Then, after BICEP1, we fielded BICEP2 and the only difference really was the fact that we used these new detectors. It gave us a factor of ten improvement in how quickly we could make these measurements. That makes a huge difference: BICEP2 was in the field for three years, so if we had kept going with BICEP1 it would have taken 30 years

You were based at the South Pole. Could you have made these crucial observations anywhere else?

Well, it's possible that you could observe at different places on Earth, but for us the South Pole is really perfect. It's got a remarkably stable atmosphere. The first thing you worry about when it comes to millimetre wave observations is water vapour in the atmosphere, so you want to go to a high site. On Earth, a high site in the South Pole is good for that, as it has about [3,048 metres] 10,000 feet of elevation. Also, because the air's so cold there, most of the water vapour has frozen out of it. The skies are very transparent and it's also very stable, because at mid-latitudes the atmosphere gets churned up by diurnal variations of sunlight and dark. Also, at the poles the Sun goes down for months at a time, so the atmosphere's very stable.

The other thing about the poles is that the field we want to observe is always up. The sky just goes around in a circle all the time – so if we move our telescope with it we can observe it all the time. Finally, the South Pole is all set up for scientific observation; there are facilities, there's a gym... it's really a top-notch place from that viewpoint as well.

When you started using BICEP2 you discovered a signal that was much stronger than you expected. What did you expect to see and why was this gravitational wave signature such a surprise?

I think there are two things: first there is the indirect recognition from the Planck satellite. It's not using polarisation, but rather the structure of the intensity variations in the background... It could have been telling us something about inflation, it may be that statistically, but this is something that gets resolved, worked out. There was that result going in [to BICEP2]. Then there was this expectation in the community, and I'm as subject to this as anyone, that we should really be designing these experiments to go very deep to look for the signal.

So, we were all geared up to even more powerful experiments, to find incredibly low numbers. When the results initially came out – I became aware of it about a year ago from our data – I was sceptical. We spent the past year just looking at every possible way

The original BICEP project team, plus the telescope body

“We spent the past year looking at every possible way the instrument could produce a false signal. We had many turns and zig-zags… but every time the data would get more consistent”

the instrument could produce a false signal. We had many turns and zig-zags through this process, but every time we would come up with a mechanism, generally we would find that after going through it, we would learn a few things about the data and it would get even more consistent. The data would still be present – we were able to find an explanation for the signal. The thing that pushed us over was that we compared our data with BICEP1, which itself doesn't have the sensitivity to produce the signal, so we could do a cross-comparison. That cross-comparison was consistent with what we were getting.

So, it gradually dawned on the team that you might be on to something? How exactly did that feel, being so close to something so significant?
Well, you know, it's funny how these things emerge and, as I said, people have different reactions… We have four leaders of the overall programme who would sit down and talk every so often just among us asking, 'Do we believe it?'

Different people would have different levels of confidence. But that wasn't good enough – just to sample people's opinions, so we'd ask, 'If you think this is wrong, what specific test should we do next?' Then we would talk about the strategy for the next two weeks, discussing what tasks we could do that would confirm or open up a line of inquiry that would tell us what was happening. We just systematically went through all the objections and thoughts of our team, taking one at a time.

The funny story is that last year, in the spring, we had actually been trying to get an upper limit paper out because we had all this great data. We just assumed that we'd be putting a maximum value on the signal level and we couldn't get any answer that was just noise. We kept seeing this extra signal – it was statistically significant and we didn't see it in any of our other tests and actually, we were pretty frustrated that we had this signal and we couldn't get rid of it! Then we had this meeting where we compared our data with [findings] from Caltech and they agreed. Suddenly, for me it was this watershed moment: 'It's real!' I thought.

What exactly is B-mode polarisation and how did it help you to finally verify the theory of cosmic inflation and in so doing the Big Bang theory?
You can mathematically decompose a pattern of polarisation into two kinds. There's one called the E-mode pattern, which has a particular kind of signature… it doesn't have a curl. You can take any pattern of polarisation and it has an E-mode part, which is basically curl-free and a B-mode part, which only has curls.

Cosmic inflation sets up density waves that are a big source of the polarisation pattern in the microwave background. In fact, that's most of the signal we can actually see – mostly E-modes. Density waves cannot make a B-mode pattern, so if you see one it cannot be made by density waves: you're led to a source that has a handedness. Gravitational waves have left- and right-handedness. Scientists have known about this since around the 1990s and there have been a number of papers released proposing that we look for this B-mode pattern as a signature of inflationary gravitational waves.

How can this signal be recognised for what it is after such a long time?

The gravitational waves from inflation – they're kind of the analogue of the microwave background. The microwave background is this afterglow of the Big Bang made up of the oldest photons we can see, it's just that they're scattered. They were created in the early universe at an earlier time from matter-antimatter annihilation. At that time the universe was very hot and those photons were bouncing around against the electrons.

Then there was this time when the universe cooled down as it expanded, when the free electrons paired up with protons and the neutral hydrogen. Next the universe became transparent. So ever since that time, which was about 380,000 years after the Big Bang, the universe was pretty much transparent to optical light. That's what we're seeing in the background, but we can't see the earlier times directly because the photons have been strongly scattered. Gravitational waves are kind of the same analogue; they're a background made from the early universe. They're much harder to detect than photons and haven't been observed directly – we've inferred them from things like orbiting pulsars.

These gravitational waves in the background don't interact with the universe from the time that it was created to a very good approximation. So it's basically been free-streaming to us from the time that inflation happened, some 10^{-32} seconds after the Big Bang. If we could see these gravitational waves directly, presumably we would detect them and we could map out their structure and all that.

By using the microwave background, we're basically using the universe as a gravitational wave-detector. The squeezing and stretching of the gravitational waves produces this polarisation pattern that we're seeing in the background.

Where do you go with BICEP now that you have made the announcement?

In the near-term the field is going to be active trying to test our instrument to see if it's verified or not. We'll be participating in that as well.

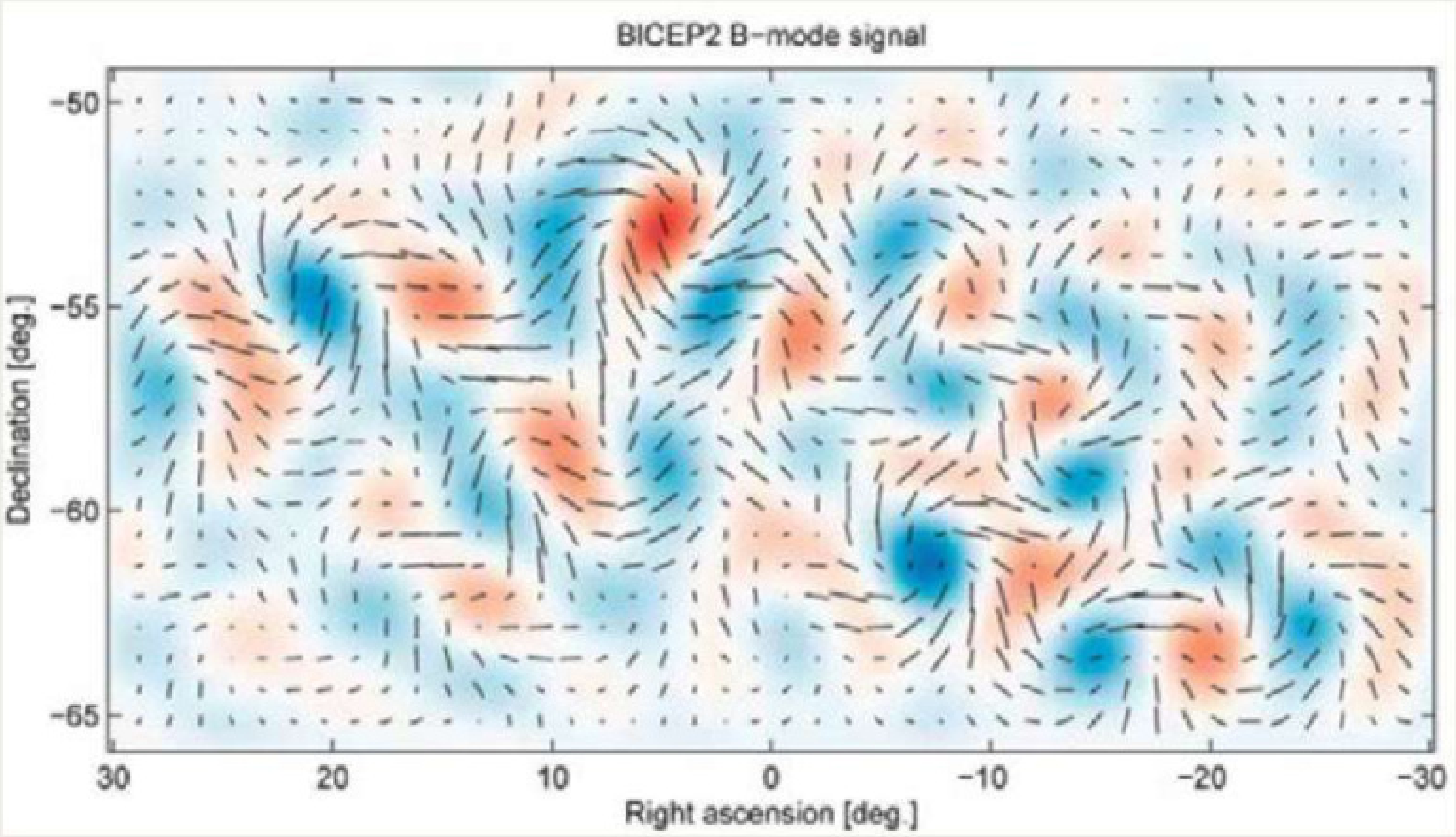
There's been a lot of talk of Nobel Prizes in the media – would you care to comment on that?

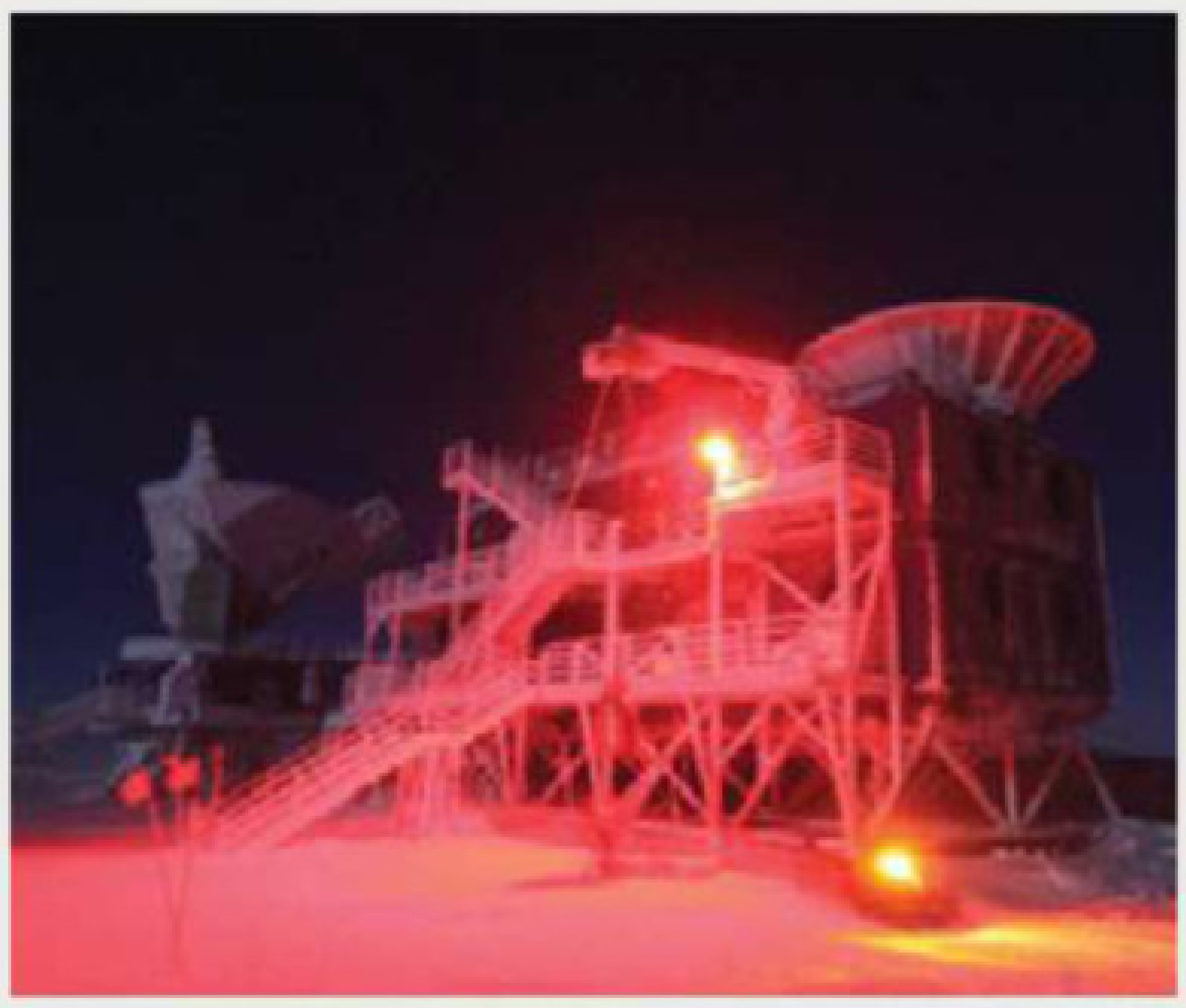
[Bock laughs] No.

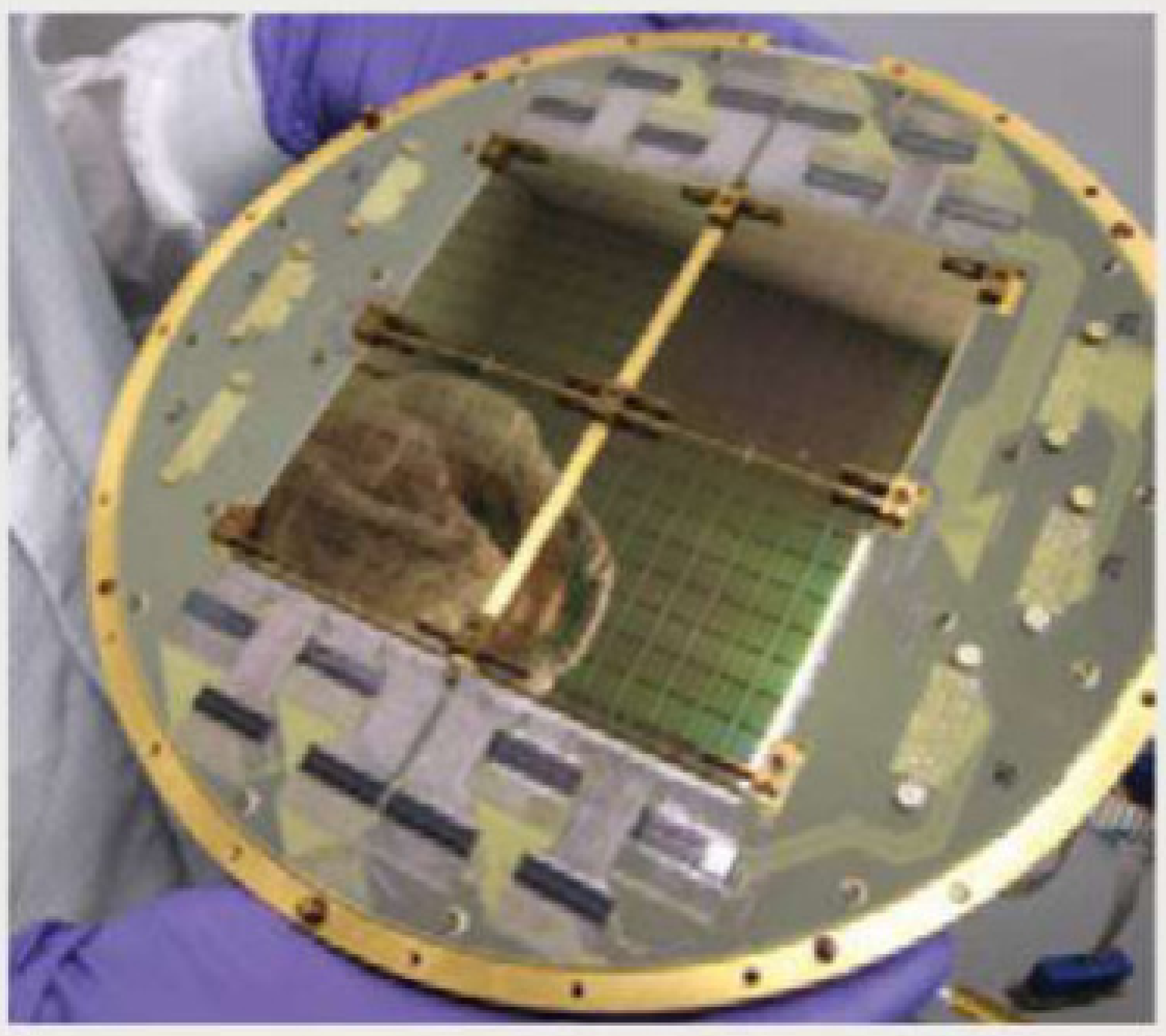
Will you be going back to the South Pole for further work any time soon?

Yes. Right now the Sun has set in the South Pole, so we're in winter mode. We're collecting data with the Keck Array, two focal points running at a different colour, at 95 gigahertz instead of 150 gigahertz. That data, in two months, should be more powerful than what we used in our paper.

When October rolls around, the season opens for summer time and we have a new experiment called BICEP3, which will be the most powerful instrument of its kind. Once the station opens we basically have from mid-October until February to bring our experiment down, get it running, calibrate, test and prepare it for cosmological observations. In the meantime we will be servicing and calibrating the Keck Array. It's going to be a busy Antarctic summer. I'm looking forward to it. ■







Clockwise from the top: A graduate tests the electronics of the BICEP2 instrument inside the Dark Sector Laboratory; the BICEP2 B-mode signal, showing a signature curl that verifies the theory of cosmic inflation; the focal plane of the BICEP2 instrument, which uses the highly specialised bolometer detectors Professor Bock worked on at JPL; liquid helium, coolant for the superconducting BICEP2 telescope, is delivered to the laboratory during the grip of the freezing Antarctic winter where in some areas darkness can preside for six months

© NASA; JPL-Caltech; Steffen Richter, Harvard University; Robert Schwarz, University of Minnesota; Anthony Turner

Messier 7

Observed in ancient times, this is one of the more violent clusters in the galaxy

Easily visible with the naked eye as a diffuse patch against the background of the Milky Way, the open star cluster Messier 7 (NGC 6475) was known about over 2,000 years ago. It was observed by the Greco-Roman astronomer Claudius Ptolemy in 130 BCE and more recently by Charles Messier in 1764 who included it in his famous catalogue.

Messier 7 is around 200 million years old, which means the Milky Way galaxy hasn't even had time to make one full rotation since this cluster was formed. The bright cluster of around 100 stars can be found 800 light years from Earth at the tail of the constellation Scorpius, in a group that spans around 25 light years in diameter. The stars formed around the same time, from the same dust cloud, and have a similar chemical composition, which means they're likely to end the same way at the same time. In fact, up to ten per cent of Messier 7's stars will finish their days exploding in a massive supernova, which will be quite a sight for anyone who's around to see it.

This new image of the Messier 7 open cluster was captured by ESO's La Silla Observatory in Chile

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National Space Academy Education Officer
■ Sophie studied Astrophysics at university. She has a special interest in astrobiology and planetary science.

Zoe Baily

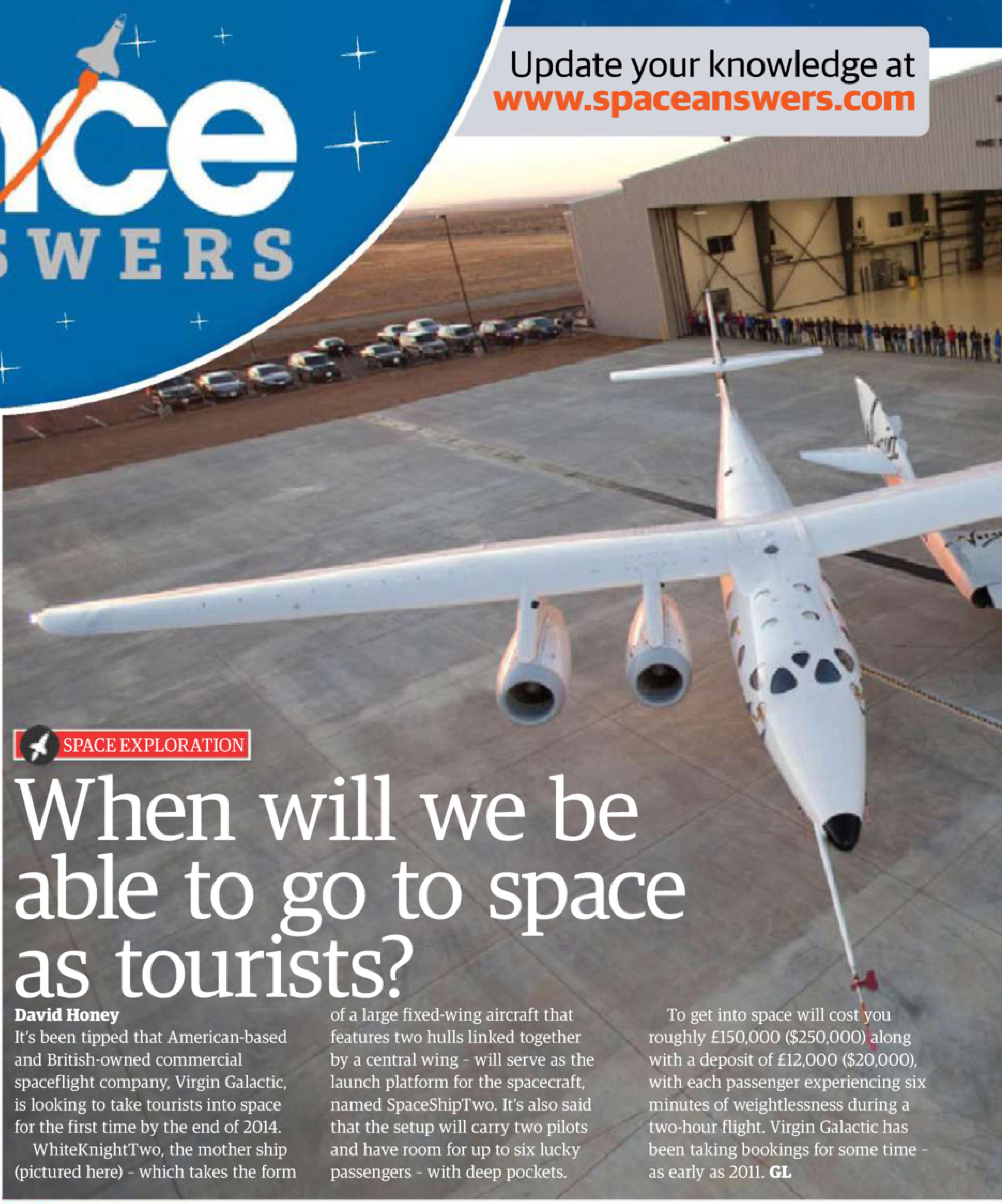
National Space Centre
■ Zoe holds a Master's degree in Interdisciplinary Science and loves the topic of space as it brings together many different scientific disciplines.

Josh Barker

Education Team Presenter
■ Having achieved a Master's in Physics and Astrophysics, Josh continues to pursue his interests in space at the National Space Centre.

Gemma Lavender

Staff writer
■ Gemma has been elected as a fellow of the Royal Astronomical Society and recently joined the **All About Space** team on a permanent basis.



SPACE EXPLORATION

When will we be able to go to space as tourists?

David Honey

It's been tipped that American-based and British-owned commercial spaceflight company, Virgin Galactic, is looking to take tourists into space for the first time by the end of 2014.

WhiteKnightTwo, the mother ship (pictured here) - which takes the form of a large fixed-wing aircraft that features two hulls linked together by a central wing - will serve as the launch platform for the spacecraft, named SpaceShipTwo. It's also said that the setup will carry two pilots and have room for up to six lucky passengers - with deep pockets.

To get into space will cost you roughly £150,000 ($250,000) along with a deposit of £12,000 ($20,000), with each passenger experiencing six minutes of weightlessness during a two-hour flight. Virgin Galactic has been taking bookings for some time - as early as 2011. **GL**

SOLAR SYSTEM

Could our Solar System survive if the Sun became a red dwarf?

Red dwarfs are the most common star type in the universe

Sasha Fox

For one thing, our system would be much colder. On Earth we live in what is known as the Goldilocks Zone. This is quite some distance from our Sun and is just the right place for liquid water to exist.

The Goldilocks Zone around a red dwarf is much closer and here on Earth we would likely freeze. Trying to live around this new star would also mean we'd have more-intense magnetic fields and violent solar flares to deal with.

Red dwarf stars are smaller and cooler than our relatively average star, the Sun. They are also the most common star type in the universe.

We think that many red dwarf star systems may have habitable, Earth-like planets that orbit them, but replacing our own star with a red dwarf would be rather disruptive to our Solar System and home planet. **ZB**

Make contact: @spaceanswers /AllAboutSpaceMagazine @ questions@spaceanswers.com

Virgin Galactic is likely to be the first craft capable of taking tourists into space

Many comets we see passing through the Solar System are likely to originate from the Oort Cloud

DEEP SPACE

What would happen if two Oort Clouds collided?

Katherine Sweet

The Oort Cloud is a theoretical group of cometary bodies located at the edge of our Solar System. It's thought that some of the comets we see pass through the Solar System come from here, and if our system has one, it's reasonable to think others could too.

Not much would happen if we passed close to an exo-Oort Cloud - although one could contain a lot of material, it's quite sparsely spread and would have little influence on any other cloud. As the two clouds interacted we'd maybe see small-scale disruption, with the inner Solar System seeing a few more comets. **JB**

ASTRONOMY

Can my telescope help to cancel out light pollution?

Anthony Crossman

There is no doubt that stargazing in urban and light-polluted areas can be tricky. You can't cancel the effect it has lighting up the skies, but there are things you can do to get the most out of your viewing.

Find a place out of direct light, even if this means hiding under a blanket. Best viewing is late into the night or in the early hours, so plan beforehand. Knowing exactly where your target is going to be at what time makes it much easier to spot. It can be difficult to view fainter objects, but don't forget that there are still plenty of fantastic sights to be seen that outshine even the brightest glows. **ZB**

Your telescope might not be able to cancel out light pollution entirely, but a variety of tricks can help minimise it

SOLAR SYSTEM

Would we have been able to live on early Mars?

Mia Grover

It's possible that we might have been able to live on an earlier Mars, although we still don't know enough about the early atmospheric conditions to be sure.

Observations of river channels and ocean beds on Mars show that the atmosphere was once much thicker, so liquid water could exist. Turn back the clock to a time when Mars still had a magnetic field, it would have been able to deflect high-energy charged particles that would otherwise strip the relatively fragile atmosphere.

Research by scientists studying the difference between surface rocks and Martian meteorites suggests that about 3.7 billion years ago Mars may have had an oxygen-rich atmosphere. So, for a short time at least, the Red Planet may have been habitable for humans. **SA**

Could we have once survived on Mars?

ASTRONOMY

What's the largest optical telescope in the world?

The Gran Telescopio CANARIAS (GTC) in the Canary Islands is currently the largest optical telescope on Earth

Leon Jackson

The largest ground-based telescope is the Gran Telescopio CANARIAS (GTC) located in La Palma on the Canary Islands. The aperture of this reflecting telescope reaches a total of 10.4 metres (34 feet) in diameter and is currently one of the most advanced in the world. It can be used to explore remote systems, galaxies, nebulas and black holes.

Although GTC is at present the largest, plans for even larger optical telescopes are currently underway. This includes the aptly named European Extremely Large Telescope (E-ELT) planned for the early-2020s. This will measure close to 40 metres (131 feet) in diameter and hopes to help us study our universe in more detail than ever before. **ZB**

SOLAR SYSTEM

Why does Neptune have dark spots?

Anne-Marie Temperley

Neptune gets dark blemishes in its atmosphere due to storms that rage in circular or somewhat elliptical spots on its surface.

The most famous of these was a gigantic anticyclonic storm in the southern hemisphere of the planet. At wind speeds of up to 2,414 kilometres (1,500 miles) per hour, this storm was recorded to be the strongest in the Solar System, discovered in 1989 when Voyager 2 made a flyby of the planet.

These features haven't always been known to stick around. When the Hubble Space Telescope looked at Neptune, the Great Dark Spot had disappeared and another had taken its place. **GL**

The dark spots on Neptune are fairly short-lived

Extraterrestrial water, such as that given out as plumes from Saturn's moon Enceladus, is likely to be too dangerous for us to drink

SOLAR SYSTEM

Can you drink water from other planets?

Hillary Wright

It's probably not a good idea! Knowing which minerals on other planets are readily dissolved in water, and in what concentrations, is pretty difficult to gauge at the moment. There's quite a high chance that any water that you attempted to bottle up and drink from another world is likely to be a sludge of acidic minerals, laden with highly toxic metals, or carrying other unsavoury materials from underground.

If we took Mars, for example, it's likely that any water found there would either be extremely acidic or highly salty. You might argue that a beverage like Coca-Cola is pretty acidic and you would be right. However, with a pH of around 2.5, our stomachs can obviously handle this drink. The Red Planet's much higher acidity, however, would cause serious internal injuries. **GL**

DEEP SPACE

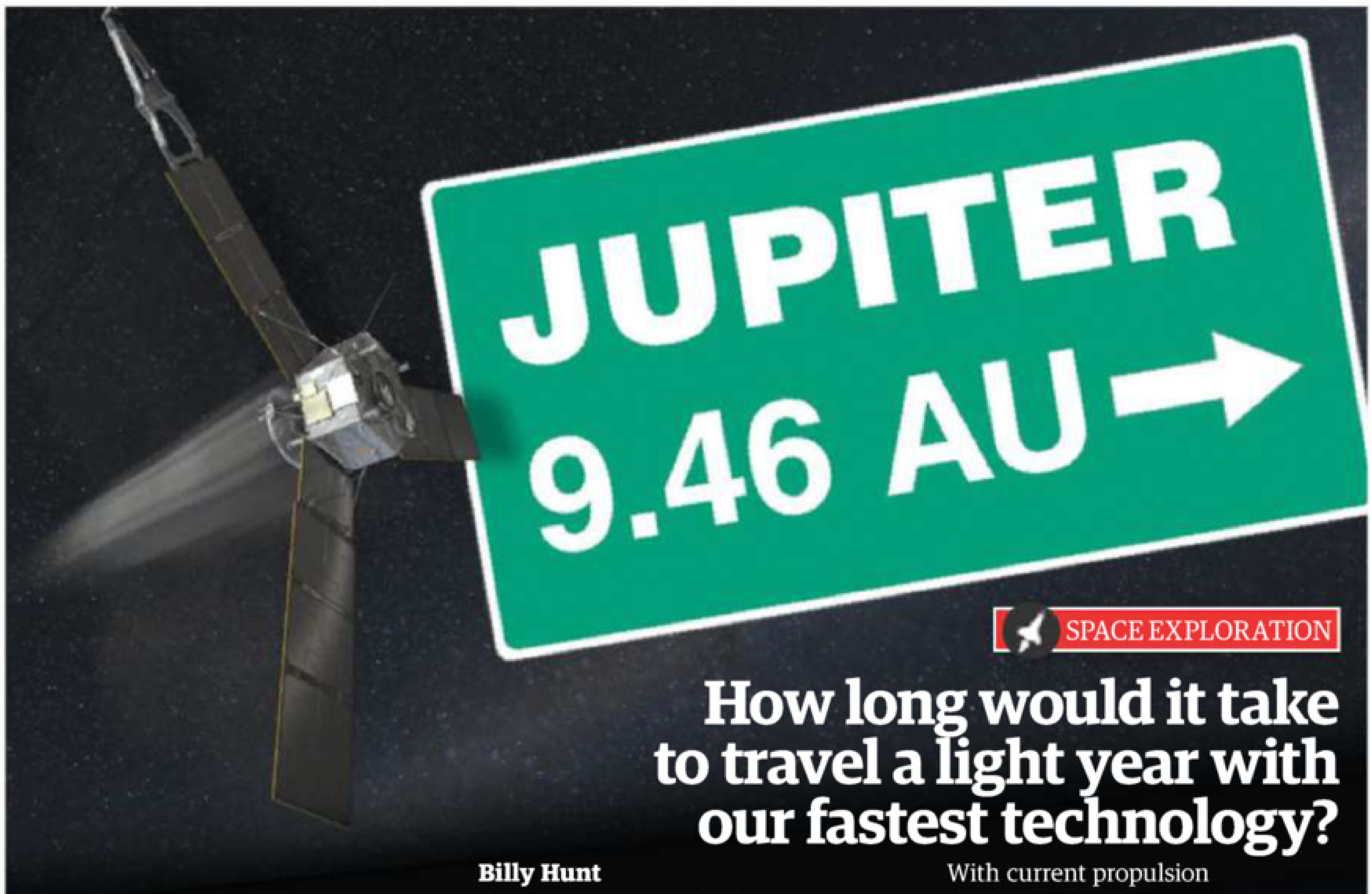
What is a hot Jupiter?

Elizabeth Perry

Hot Jupiters are exactly what their name suggests. These alien worlds are made of gas (just like their prototype) and are often found orbiting extremely closely to their star – very much closer than Mercury is to our Sun. In fact, some get so hot that their surfaces are often found to reach up to several thousand degrees Celsius. In short, the star roasts the planets' gases.

Hot Jupiters are fairly exotic, at least by the standards of our Solar System, with some of these sweltering worlds possibly having clouds of molten rock shifting through their skies. They are also likely to be tidally locked, with one side of these worlds facing the star and the other pointing out to freezing-cold space. **GL**

Hot Jupiters are huge worlds made of gas that's heated to super-high temperatures



SPACE EXPLORATION

How long would it take to travel a light year with our fastest technology?

Billy Hunt

The fastest man-made object ever created is NASA's Juno spacecraft en route to Jupiter. It is travelling (with the aid of gravitational slingshot manoeuvres) at a tremendous 40 kilometres (25 miles) per second relative to the Earth. At this speed it would take it 7,500 years to travel one light year.

With current propulsion technology, using the gravity of another planet to gain a speed boost is the only way to accelerate fast enough for deep-space exploration. No other current propulsion technology can even come close to this, meaning we still have a long way to go before a light year becomes a realistic distance to travel. **SA**

It would take Juno – our fastest spacecraft to date – 7,500 years to travel one light year

Quick-fire questions

@spaceanswers

What is meant by CME?

CME is short for coronal mass ejection. These great bursts of wind and magnetic fields are thrown out from the Sun's surface and into space.

What is Saturn's atmosphere made of?

The ringed planet's atmosphere is made up of hydrogen (75 per cent) as well as helium, with traces of other substances like methane and water ice (25 per cent).

How many exoplanets have we found so far?

As of 4 April 2014, we have uncovered 1,780 individual planets in 1,103 planetary systems, which include around 460 multiple planetary systems.

How old is the Moon?

Our natural satellite is around 4.5 billion years old.

How many stars are in the Andromeda galaxy?

There are around a trillion stars in the Andromeda galaxy.

What exactly is the colour of the universe?

According to a team of astronomers from John Hopkins University, the average colour of the universe is beige – they call it Cosmic Latte!

Which planet rains glass from the sky?

Super-hot blue alien world HD 189733b, just 63 light years away from Earth, supposedly rains molten glass from its atmosphere.

What's the biggest moon in the Solar System?

With a radius of 2,630 kilometres (1,634 miles), Jupiter's moon Ganymede is the largest moon in our Solar System.

What is a bullet cluster?

This is the name of a pair of colliding clusters of galaxies. The term 'bullet cluster' actually refers to the smaller subcluster, which is found speeding away from the larger one.

Quick-fire questions

@spaceanswers

What is M-theory?
This theory of particle physics consists of a universe of 11 dimensions where weak and strong forces, as well as gravity, are unified. M-theory is an extension of string theory.

Who was the youngest person in space?
At 25 years old, Gherman Titov was the youngest person in space aboard Vostok 2 in August 1961.

When is the next mission to Mars planned?
Unmanned lander mission, InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) is slated for launch in March 2016.

Why were the Space Shuttles white?
A white paint makes for a much better heat-reflective surface when the shuttle eventually re-enters the Earth's atmosphere.

What are the Hyades?
The Hyades, also known as Melotte 25 or Collinder 50, is the nearest open star cluster to our Solar System.

Does Pluto actually have an atmosphere?
Yes, it's a thin envelope of mostly nitrogen frozen when the dwarf planet is far away from the Sun, changing directly from solid to gas when it approaches our star.

When will Hubble finally be decommissioned?
With a mission length of 24 years, it's expected that Hubble will continue to function anywhere between 2014 and 2020.

Can we see Saturn's moons from Earth?
A 5cm (two-inch) telescope will show you Titan, while half a dozen of the ringed planet's moons are within reach of larger 25cm (ten-inch) instruments.

It seems the bulky spacesuit is here to stay!

SPACE EXPLORATION

Why are spacesuits so bulky?

John Strickland

Spacesuits appear very padded and cumbersome - and, in general, not very streamlined - since they must provide a certain pressurised volume for the astronauts wearing them.

It's highly likely that the spacesuits we see astronauts wearing today bear a design that's here to stay for some time. Despite seeming quite big and hard to work in, many spacewalkers report that they're indeed reliable and accommodate for a wide range of astronaut sizes.

Another factor is cost. With other designs for the spacesuit investigated, it's not possible to make spacesuits less bulky while keeping the price for making one down.

That said, however, the spacesuit is now undergoing minor improvements, such as enhanced thermal materials, better gloves and much improved helmet lighting. **GL**

ASTRONOMY

How does MAGIC work?

Terry Brown

The Major Atmospheric Gamma-ray Imaging Cherenkov Telescopes (MAGIC) comprises two scopes that operate in gamma ray wavelengths with 17-metre (56-foot) mirrors.

These rays release showers of particles that are detected by the telescopes using the faint light given off by the charged particles in these showers. Being unaffected by magnetic fields, the electromagnetic particles act as messengers that tell us all about the cosmos.

So far, the pair of telescopes - situated at the Roque de los Muchachos Observatory on La Palma - have strengthened the known constraints of dark matter models. **GL**

MAGIC-I (pictured here) works with MAGIC-II to probe the universe

We can't hear supernovas, but if we could, we'd definitely want to be wearing some form of ear protection!

DEEP SPACE

If we could hear a supernova, what would it sound like?

Tom Williams

Sound itself can only be transmitted through a medium and so in space we cannot hear a supernova. However since a supernova is a giant explosion triggered by the final death throes of a massive star, if we could hear it, we would hear an incredibly loud blast. Some scientists have gone a step further and actually tried to translate the huge amount of electromagnetic radiation produced by a supernova into sound.

So, what does a supernova sound like when you translate the high-frequency electromagnetic radiation into lower-frequency sound? Well, a lot like a massive explosion! **SA**

Voyager's principal investigator, Ed Stone, standing next to a model of the space probe

SPACE EXPLORATION

What is the time difference between Voyager 1 and us?

William Deep

At its current distance, the radio signals take over 35 hours to travel from the probe to the receiver. Since its launch, Voyager 1 has been travelling for over 36 years and has clocked up over 127 times the distance between the Earth and the Sun. Being so far away, there's a considerable delay between signals being sent from the probe to them arriving.

Such a delay can result in the signal being very spread out and weak. Signals received from Voyager are on average transferred at 160 bits (20 bytes) per second. Data collection is also slow, as is waiting for the probe to react to a command from Earth. **JB**

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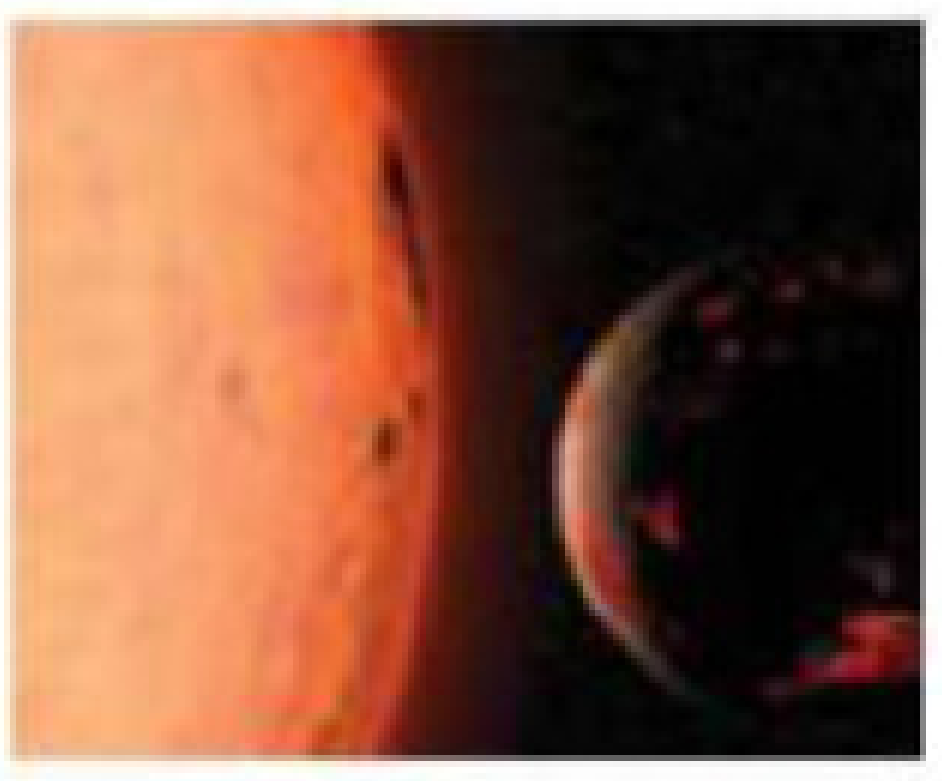
THE QUEST TO CONQUER SPACE: PART 1

10 amazing technologies that will take us to Mars and beyond



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GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

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Armchair astronomy

Fancy giving astrophysicists a helping hand with their data? Read on to discover how you can contribute to citizen space science

Many believe that you have to be a fully qualified scientist to get your hands on the data encoded in our universe. Traditionally, this information would be thrown back to Earth by spacecraft gliding through our Solar System, or gathered by the multi-wavelength, ground-based telescopes that peer into the farthest reaches of the cosmos.

However, this is no longer the case. Gone are the days when you need a PhD in space science to be able to have a good look around the universe, with the chance of making a discovery. In fact, professional astronomers need *you* to trawl through the reams of data that they've managed to accumulate from astronomical instruments of past and present, due to the sheer volume. In doing so, they're offering the chance to get in on the action of real science.

The added bonus is that you can study everything from the surface of planets, such as Mars, all the way over to the stars populating distant galaxies, all from the comfort of your very own armchair.

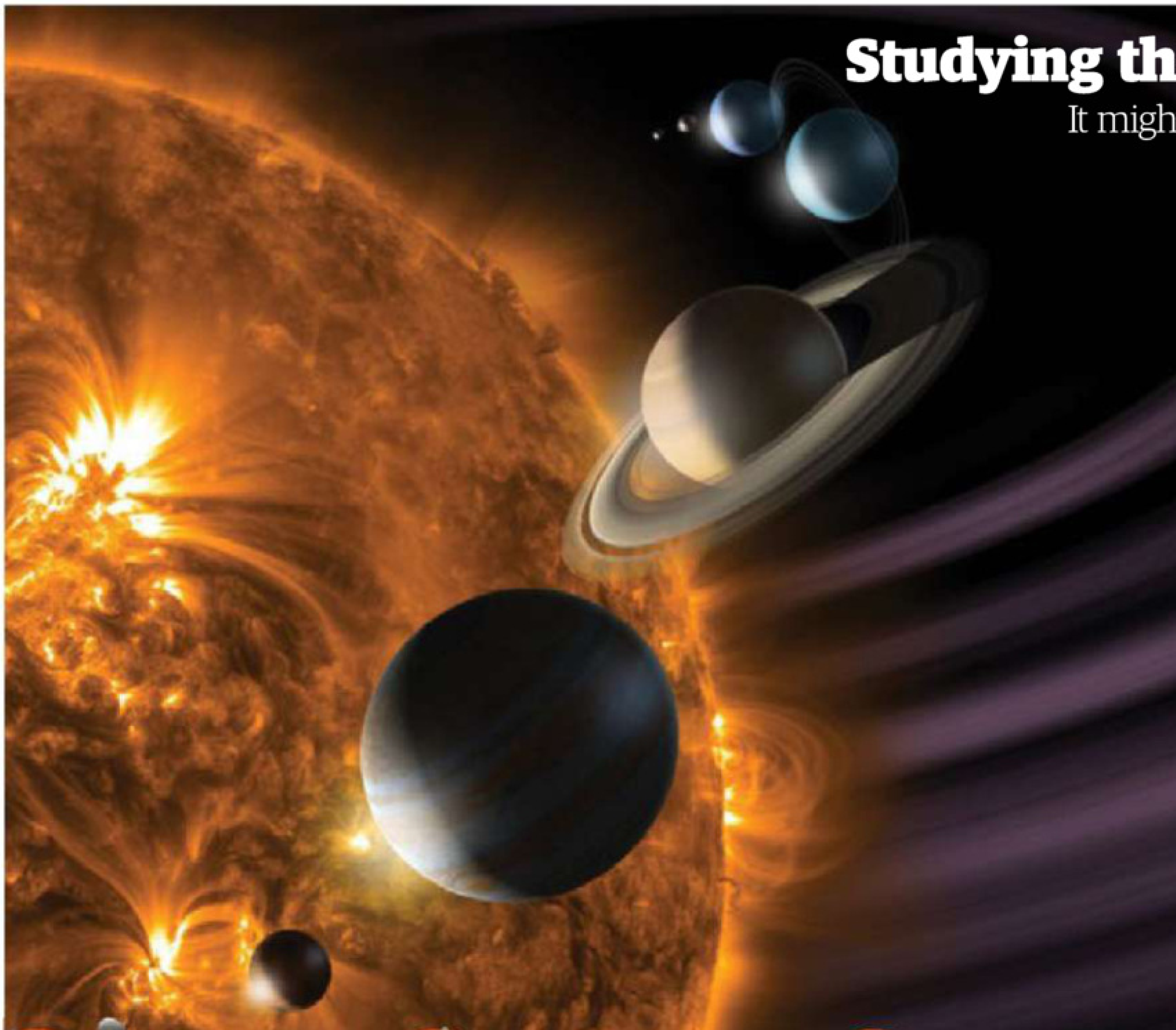
Getting out there under the stars, in the practise of amateur astronomy, is of course citizen science in itself, as astronomers turn their instruments to the heavens and often find themselves reporting the discovery of a comet or even a near-Earth asteroid. These findings give us the opportunity to paint a bigger picture of what's beyond the protective boundary of Earth.

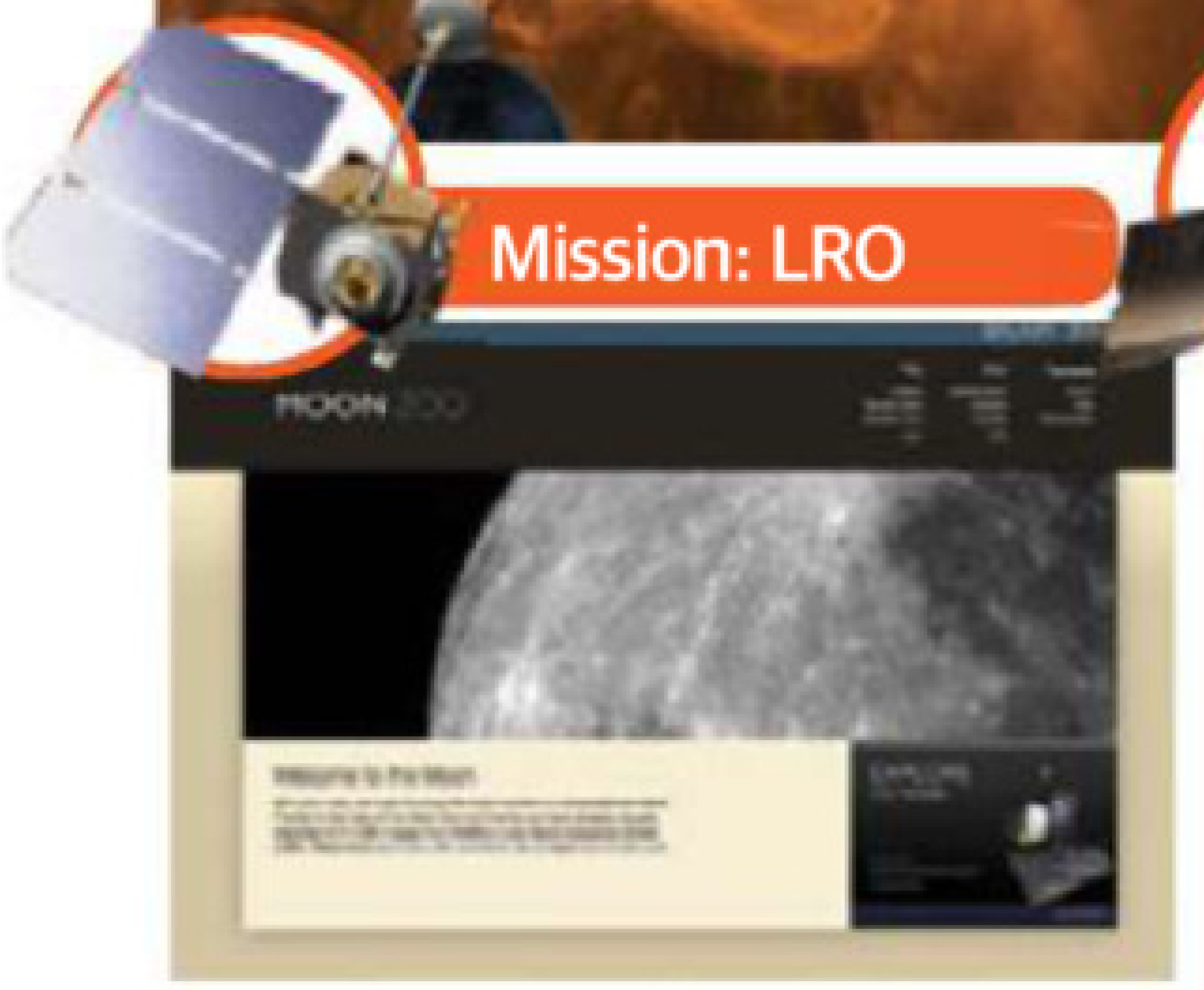
Even better, by swapping the telescope for a computer, a few clicks of a mouse has led members of the public to make their own unique discoveries. Citizen science project Galaxy Zoo has discovered Hanny's Voorwerp, a green astronomical object of unknown nature. Also, planet PH1b was discovered in the quadruple star system Kepler-64 by volunteers of Planet Hunters.

The universe really is your oyster, so here's our guide to some of the best space science projects full of undiscovered gems.

Studying the Solar System

It might feel familiar like home, but there's still plenty to explore





Moon Zoo

Part of the larger Zooniverse project, which began with the introduction of Galaxy Zoo, the Moon Zoo citizen space project (**www.moonzoo.org**) lets you study the lunar surface in unprecedented detail using images snapped by NASA's Lunar Reconnaissance Orbiter (LRO), which is currently circling the Moon.

The Moon Zoo community has visually classified nearly 4,000,000 images, so your task is to draw attention to any noticeable feature that may interest scientists - whether it's a crater, boulder or unusual feature protruding out of the lunar landscape. When finished, your hard work will be saved to the Moon Zoo database.

Planet Four

It might have the likes of the rovers Curiosity and Opportunity trundling across its surface, but experts are still calling on the general public, or citizen scientists, to assist the craft surveying the Red Planet in a project dubbed Planet Four (**www.planetfour.org**).

Analyse the Mars Reconnaissance Orbiter (MRO)'s images to explore the surface of our neighbouring world, where you can highlight any strange features such as blotch-shaped characteristics that pepper the dry and barren landscape of the fourth planet from the Sun. Who knows, maybe you could discover something new that's so far escaped the notice of the professional astronomers!

Target Asteroids!

Asteroids, or near-Earth objects (NEO), have been of interest to amateur astronomers on a long-term basis, so it's unsurprising they're called upon to contribute to the new citizen scientist project currently titled Target Asteroids! (**www.asteroidmission.org**).

The aim is for amateur astronomers to make observations and directly support the asteroid sample-return mission OSIRIS-REx, that's planned for launch to asteroid Bennu.

You'll need an interest in astronomy and access to appropriate observing equipment to take part. Through this project you can help experts refine orbits and determine the composition of these members of our Solar System.

Solar scientists need you!

Help them spot explosions on the Sun and track them across space to Earth. Your work will give astronauts an early warning if dangerous solar radiation is headed their way. And you could make a new scientific discovery.

Solar Stormwatch

We all know that the Sun has plenty of impressive and unpredictable activity bubbling away on its surface. Due to solar flares and coronal mass ejections that angrily burst from its surface, our star can be extremely dangerous.

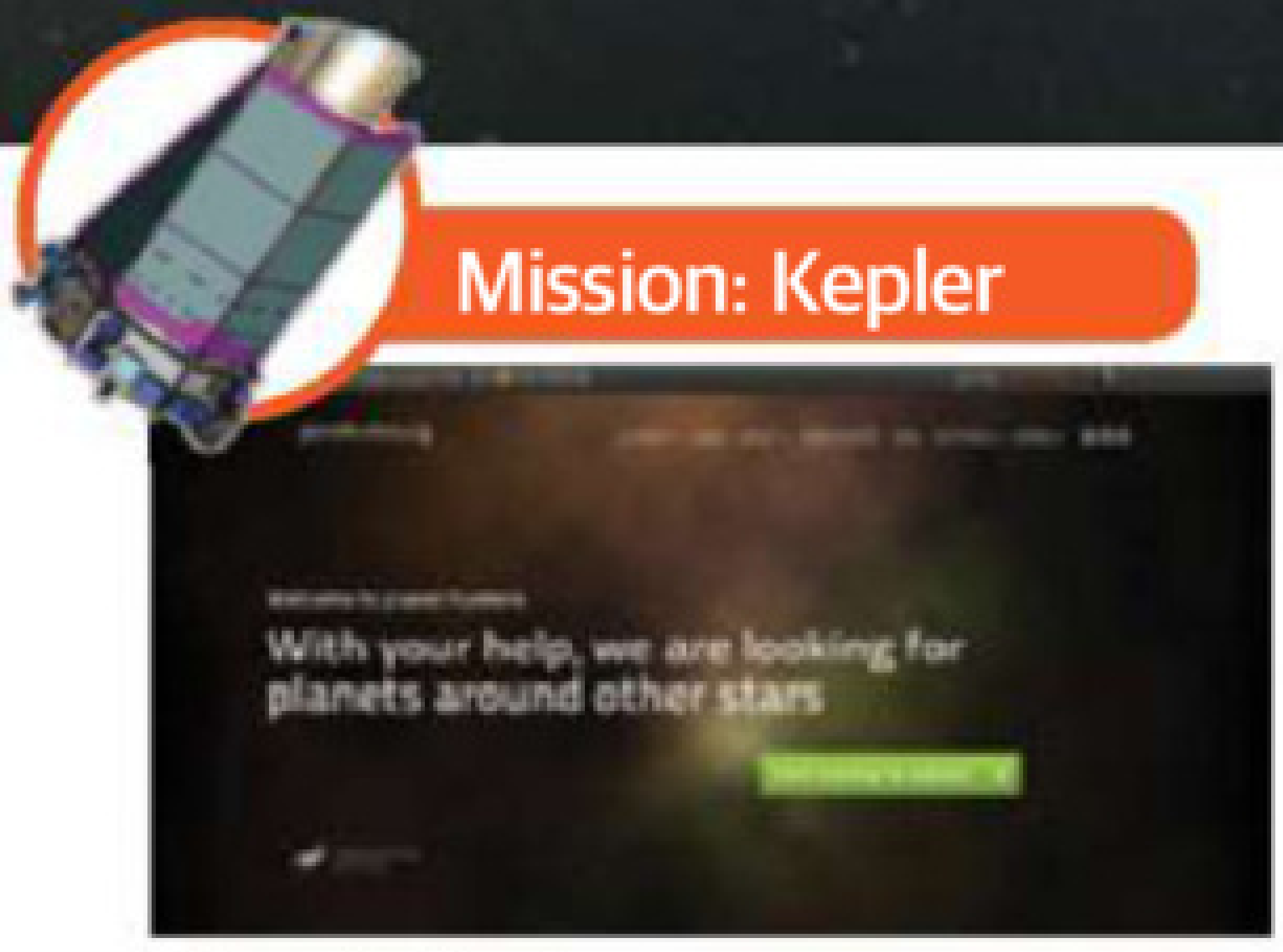
This is why solar experts need your help in tracking these solar eruptions across space (**www.solarstormwatch.com**). Not only are you able to keep astronauts safe by giving them an early warning sign for when dangerous solar radiation could be heading their way, but you could also make new scientific discoveries.

Hunting for other worlds

There are billions of worlds out there, so why not help expert planet hunters track down and define them?

Find the Birthplace of Planets

Mission: Kepler



With your help, we are looking for planets around other stars

Planet Hunters

Computers might be sifting through the data returned by NASA's planet-searching spacecraft, Kepler, but the experts behind the Planet Hunters project are sure there are many planets the machines are failing to detect currently. It's said that the remarkable human ability for recognising patterns could be the answer to finding the worlds that have so far eluded our technology.

Fancy being the one to beat the machines to it? Your job is to flag up any dips in brightness on what are known as light curves to find any planets that could be hidden in the Kepler data - you may even find Earth 2.0 in the space telescope's findings!

Mission: WISE

Disk Detective

All the planets that litter the universe have to come from somewhere, so Disk Detective looks at discovering more about their birthplaces - the dusty debris disks that circle a star and from which planetary systems are born.

Your mission, if you choose to accept it, is to use data gathered by the WISE spacecraft (now known as NEOWISE) to sort out the stars that have disks of debris around them from those that don't.

It's easy for a computer to confuse these disks with other astronomical objects, so your contribution in analysing the stars in distant galaxies and nebulae can help professional astronomers immeasurably.

Project: LCOGT

Agent Exoplanet

With the Las Cumbres Observatory Global Telescope network's (LCOGT's) Agent Exoplanet, you're put in the shoes of the professional astronomers who measure the dips in a star's brightness as an exoplanet passes across its surface. From this we're able to get data about the planet - such as how long it takes for the world to orbit its star, as well as the planet's mass and size.

Planet hunters are looking for members of the public to help analyse the reams of exoplanet data gathered by the LCOGT's integrated set of robotic telescopes to discover more about the exoplanets turning up. These are found in Hawaii, Australia, Chile, South Africa and Texas.

Telescope: Arecibo

SETI@Home

We know that there are other planets out there, but what about other intelligent life forms? Seeking any and all hints of life elsewhere is SETI, which is short for the Search for Extra-Terrestrial Intelligence.

As we have seen with the previous citizen science projects, there's usually a certain degree of data analysis involved, but with SETI@Home all you need to do to be part of it is run the software - known as the Berkeley Open Infrastructure for Network Computing, or BOINC for short.

This will work in unison with other internet-connected computers that also download and analyse radio telescope data from the largest radio dish in the world, the Arecibo radio observatory in Puerto Rico.

Tour of the galaxies

Packed with gas, dust and stars, galaxies also give off a treasure trove of data ready to be probed by you

Mission: Hubble

Galaxy Zoo Hubble

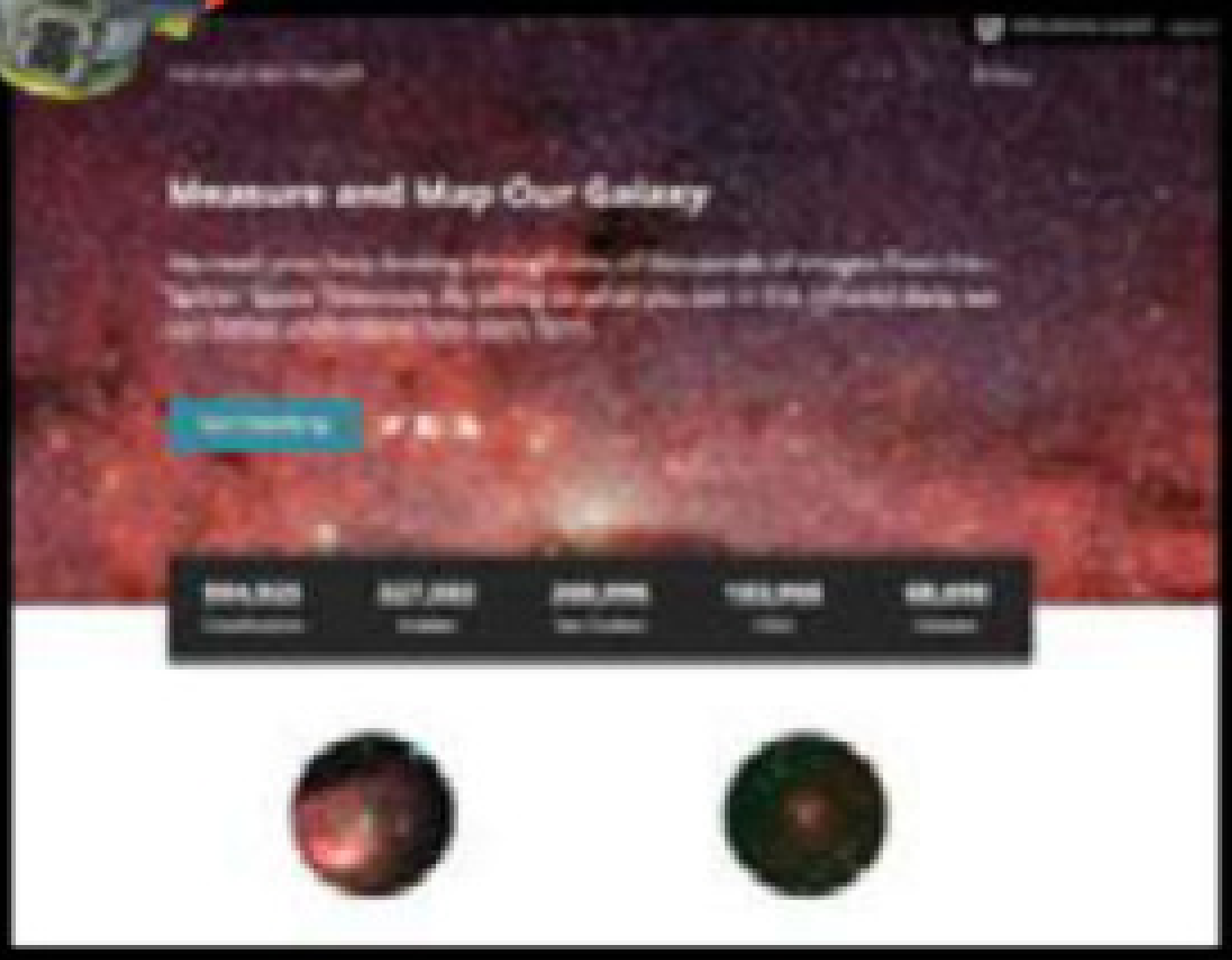
The long-serving Hubble Space Telescope has been pinging images of our universe back to Earth since its launch in 1990. Not only is the spacecraft's pictorial data stunning in its own right, its main instruments observe in the near-ultraviolet, visible and near-infrared wavelengths, providing a mine of information. When teamed up with data from the Sloan Digital Sky Survey (SDSS) and ground-based UKIRT, this gives Galaxy Zoo a whole wealth of data to contend with.

The main aim of Galaxy Zoo, which originally went live in 2007, is to help astronomers get to the bottom of how galaxies form. To assist with this, the Zooniverse project offers citizen scientists to classify galaxies in photographs in order of shape. Whether you find spirals, barred spirals or elliptical structures, you will help experts to crack the big questions, such as how these collections of stars even exist.

Few have witnessed what you're about to see

Classify Galaxies

Mission: Spitzer



Measure and Map Our Galaxy

Milky Way Project

Living in a galaxy helps us to get a bit more of an understanding of these structures in general, as well as the many different types of stars and planets that exist within the Milky Way. However, that's not all. Despite living within our galaxy, there still remains a lot of unexplained and undiscovered aspects of our galaxy.

Just like Planet Four and Moon Zoo, the idea is to classify objects in the Milky Way, being sure to point out the likes of star clusters, other galaxies in the distance as well as bubbles. Given how massive our galaxy really is, there's also a possibility that you will find something truly extraordinary – with all the fantastic images courtesy of the Spitzer Space Telescope.

Mission: Hubble

Andromeda Project

The Andromeda Project is citizen science in the galaxy next door. We know that it's the closest spiral to us, it's packed with a trillion stars and it weighs in at over 1,000 billion times the mass of the Sun. We have a good idea of all of these features, among others, but what we don't know too much about is the evolution of this gigantic structure during its nine billion years of existence.

The project is looking at rolling in more data from Hubble during 2014, enabling you to get classifying stellar clusters and distant galaxies. With your help, combined with other citizen scientists, we could be piecing together Andromeda's past much sooner than ever imagined.

Project: Australian Telescope Compact Array

In Search of Erupting Black Holes

Radio Galaxy Zoo

It's not just the optical side of galaxies that citizen scientists can find themselves getting stuck into. Objects that can't be directly observed – supermassive black holes found at the centre of galaxies – are also fair game.

You might be wondering how it's possible to hunt for these heavyweight objects when we can't actually see them. With radio wavelengths and the telescopes that operate in this waveband, we can witness the jets of material that they spit out after gorging on gas and dust.

With your help in finding them, astronomers are hoping to understand how black holes of all masses form and evolve – so the more you come across, the better!

> "You will help experts to crack the big questions"

A world of citizen astronomy

Control some of the world's most exotic telescopes from the comfort of your own home

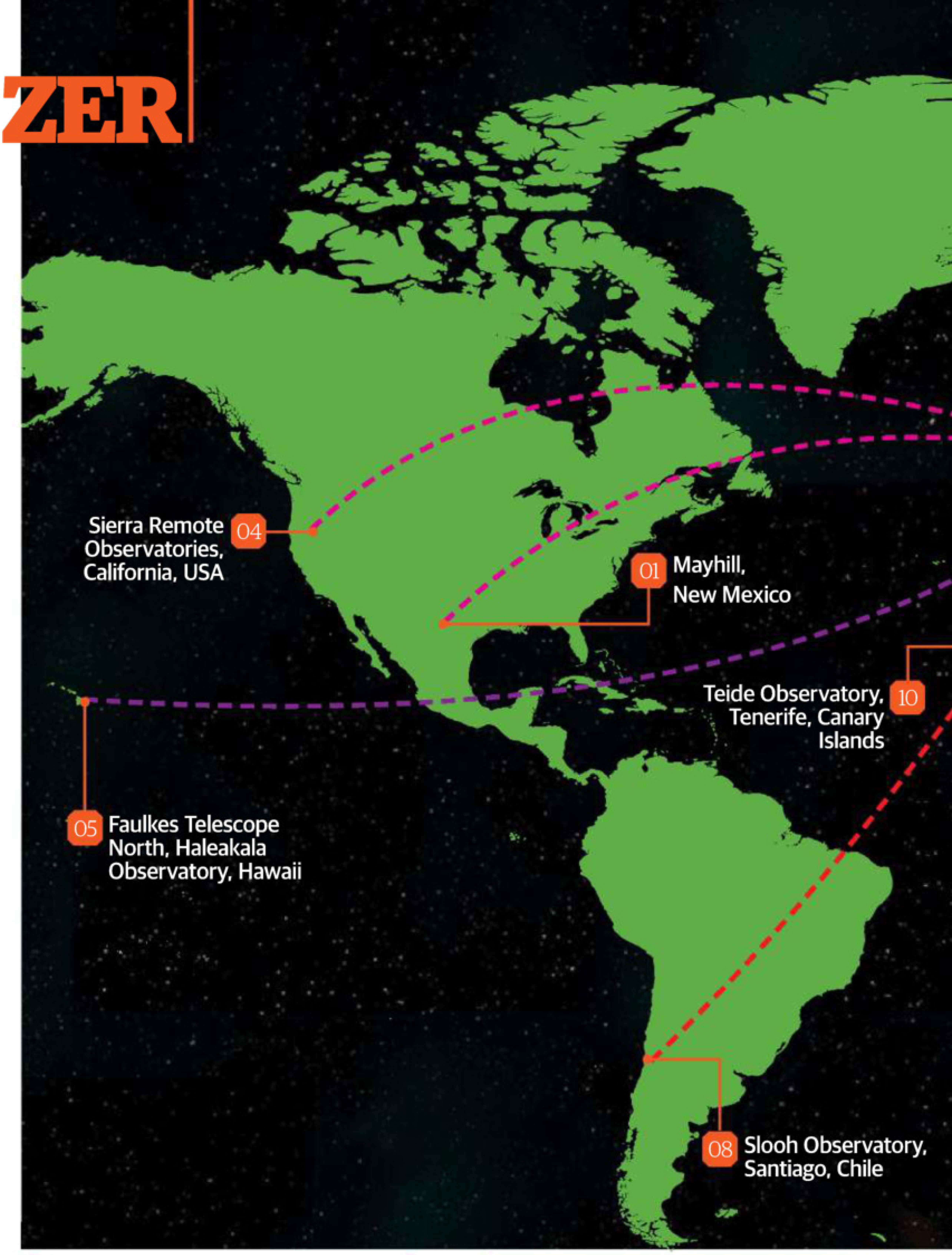
When you hear the term armchair astronomy, you're most likely envisioning a scientist sitting in a chair reading heavy tomes covering all manner of topics in astronomy and astrophysics.

In fact, armchair astronomy employs technology that many professional astronomers just can't live without. With the helping hand of the internet, you don't just have access to a huge amount of space-related information, but also the largest telescopes all over the world at your fingertips. Based under exotic skies, these great telescopes enable you to point at any object in the sky and the great thing is you don't need to be in the same country. In other words, you're using these powerful instruments remotely, just like the scientists who control interplanetary robotic spacecraft that image the Moon and travel long distances to planets.

With today's high-speed internet access and advanced browser-based programming, anyone with an internet connection can now escape their overcast or light-polluted environment to sites with some of the clearest skies in the world. Not only can you skip through the skies of New Mexico and Spain to Australia and beyond, you will also be using equipment worth a fortune.

While you don't get the chance to look through the eyepiece as you would at home or at a society meeting, controlling an observatory in another country is mind-boggling in its own right. With a few clicks of a mouse you could be using a telescope under a pitch-black foreign sky, observing and imaging deep-sky objects that you might never have seen before. Your mouse and keyboard really do serve as a doorway to the universe!

The Observatorio del Teide is just one of the many huge devices that you could take direct control of


04 Sierra Remote Observatories, California, USA
01 Mayhill, New Mexico
10 Teide Observatory, Tenerife, Canary Islands
05 Faulkes Telescope North, Haleakala Observatory, Hawaii
08 Slooh Observatory, Santiago, Chile

Slooh

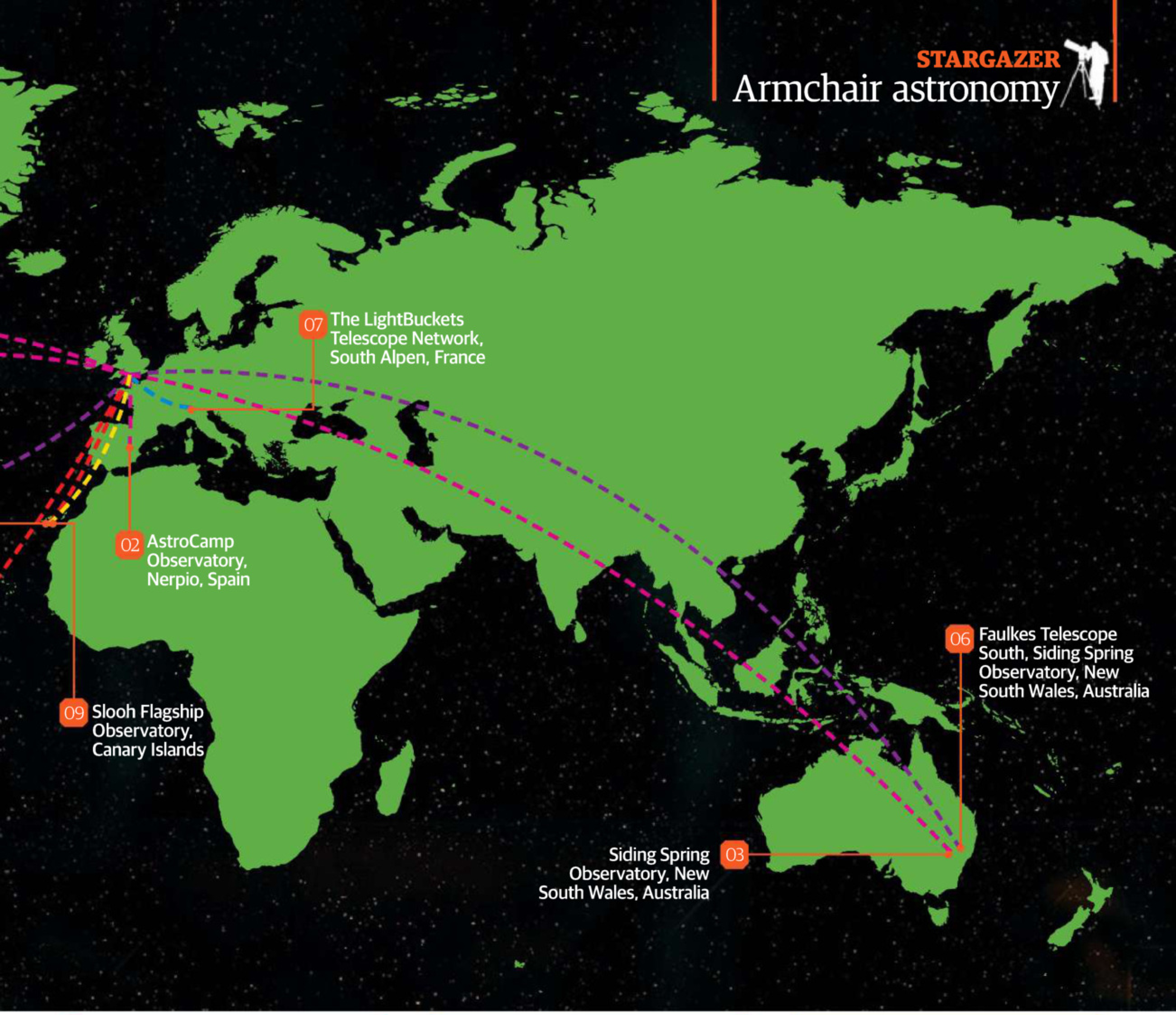
Telescopes: 8&9
Website: http://events.slooh.com
Price: Free
Ability: Beginner / suitable for kids

Slooh doesn't offer an extensive network, but does give membership to use its telescopes for free. You'll also find you have the option to be guided through live imaging sessions by an astronomer. Slooh gives full guidance on controls, which are so simple that children can get involved. There are even observing programs for young astronomers.

Faulkes Telescope Project

Telescopes: 5&6
Website: www.faulkes-telescope.com
Price: Free
Ability: Beginner / suitable for kids

A partner of the Las Cumbres Observatory Global Telescope Network (LCOGTN), the Faulkes Telescope Project provides free access to its two-metre (6.6-foot) robotic telescopes. Similar to other organisations hosting overseas telescopes, the Faulkes Telescope Project provides full training for anyone wanting to get the most out of amateur astronomy.


07 The LightBuckets Telescope Network, South Alpen, France
02 AstroCamp Observatory, Nerpio, Spain
09 Slooh Flagship Observatory, Canary Islands
06 Faulkes Telescope South, Siding Spring Observatory, New South Wales, Australia
03 Siding Spring Observatory, New South Wales, Australia

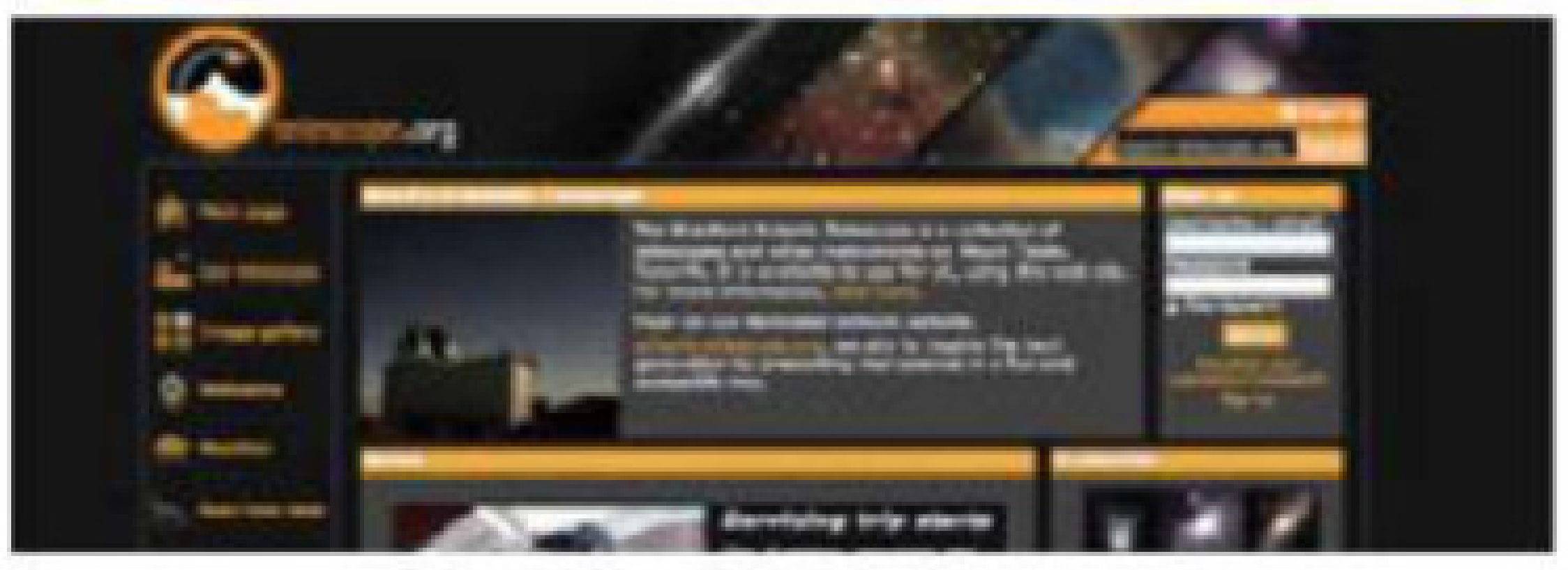
iTelescope

Telescopes: 1,2,3 & 4
Website: www.itelescope.net
Price: From £11 ($19)
Ability: Advanced
iTelescope operates a network of nearly 20 telescopes in three locations across both the Northern and Southern Hemispheres. Being in two different hemispheres gives a huge advantage, as if the skies aren't clear in one, you can switch to the other. Time using the telescopes can be bought in packages ranging from a starter trial at £11 ($19).

LightBuckets

Telescope: 7
Website: www.lightbuckets.com
Price: Prices vary
Ability: Beginner
LightBuckets presents a simple setup that leads the user through choosing an observatory, target, as well as an imaging run. It will also automatically produce final full-colour images, so there's no need to know anything about image-processing. If you see yourself as advanced, you can take complete control of the observatory and command of your imaging run.

Bradford Robotic telescope



Telescope: 10
Website: www.telescope.org
Price: Free
Ability: Beginner / suitable for kids
The Bradford Robotic Telescope (BRT) is often used by schools and colleges, making it one of the favourites for astronomy outreach. The BRT is also free to use, unfortunately meaning that telescope time is heavily over-subscribed. The system features multiple power backups and can cater for any teething troubles it may encounter.

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What's in the sky?

Darkness is fleeting in the Northern Hemisphere's summer, but there's still plenty to see if you're prepared to stay up late

The Omega nebula M17

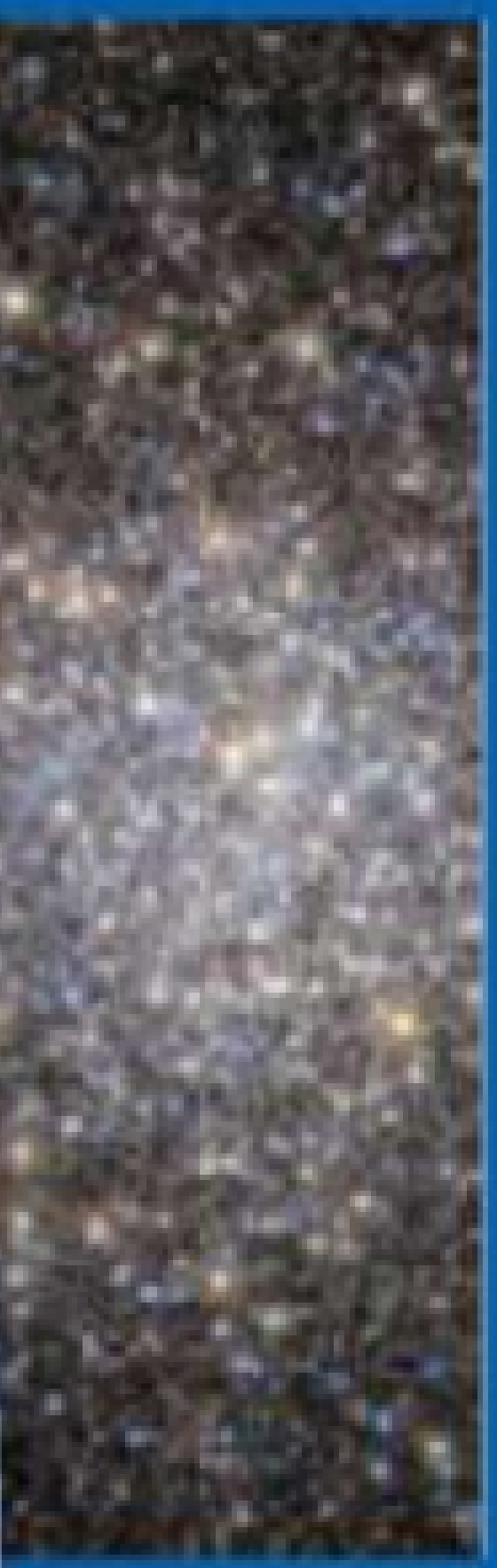
Viewable time: An hour or two either side of midnight

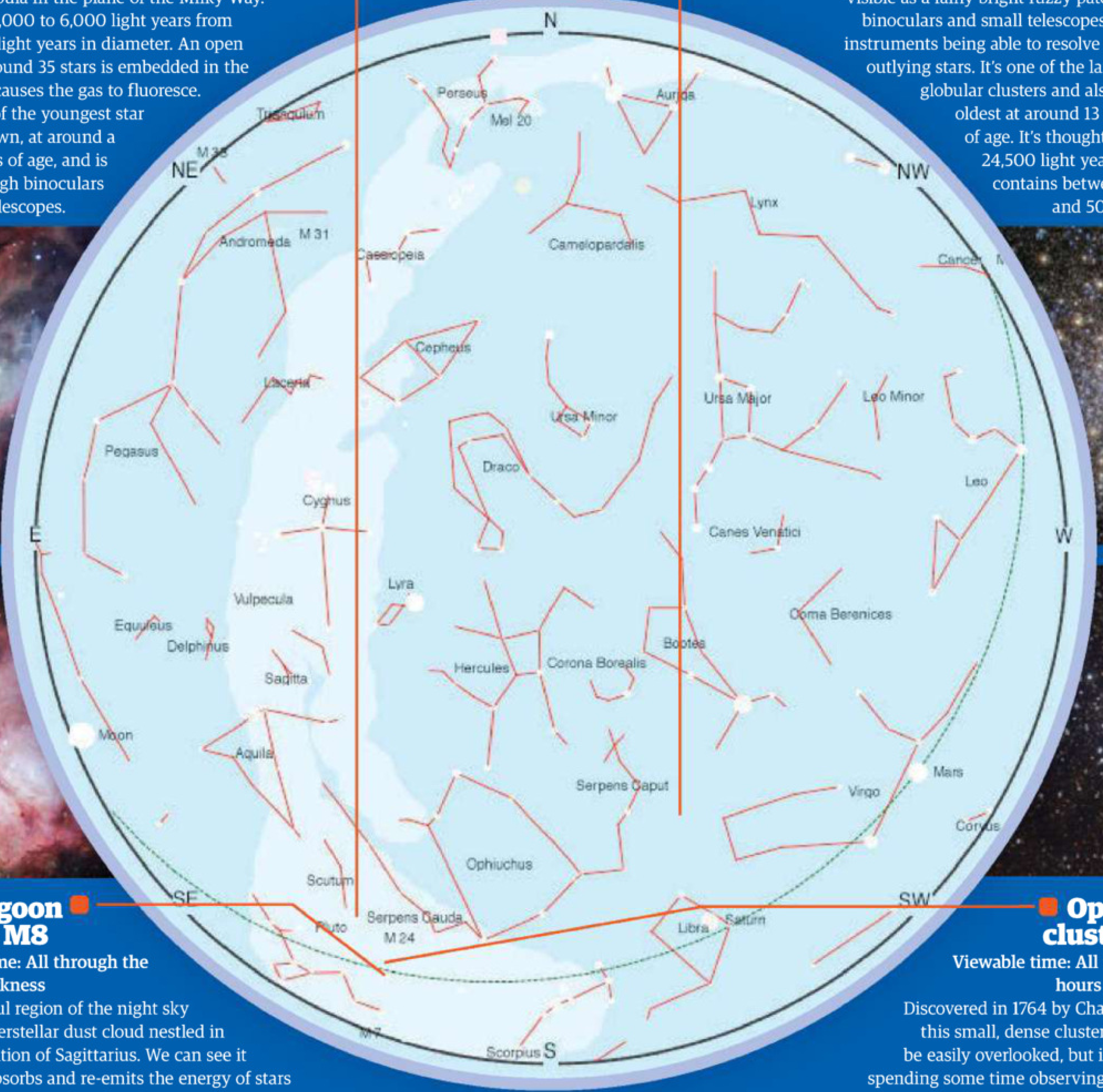
Also known as the Swan nebula, this is another emission nebula in the plane of the Milky Way. It's around 5,000 to 6,000 light years from us and is 15 light years in diameter. An open cluster of around 35 stars is embedded in the nebula and causes the gas to fluoresce. This is one of the youngest star clusters known, at around a million years of age, and is visible through binoculars and small telescopes.

Globular star cluster M5

Viewable time: All through the hours of darkness

Found in the constellation of Serpens, M5 is visible as a fairly bright fuzzy patch of light in binoculars and small telescopes, with larger instruments being able to resolve many of the outlying stars. It's one of the largest known globular clusters and also one of the oldest at around 13 billion years of age. It's thought to be about 24,500 light years away and contains between 100,000 and 500,000 stars.





Northern Hemisphere

The Lagoon nebula M8

Viewable time: All through the hours of darkness

This beautiful region of the night sky is a giant interstellar dust cloud nestled in the constellation of Sagittarius. We can see it because it absorbs and re-emits the energy of stars buried within and is therefore known as an emission nebula. You can see it as a faint misty patch of light in binoculars and small telescopes. Long-exposure photography shows it at its best and it's thought to lie between 4,000 to 6,000 light years away from us.

Open star cluster M21

Viewable time: All through the hours of darkness

Discovered in 1764 by Charles Messier, this small, dense cluster of stars can be easily overlooked, but is well worth spending some time observing, as it shows up well in binoculars or small telescopes. It's a relatively young cluster, estimated to be around 4.6 million years old and contains 57 stars. It holds a few blue giants, but the rest are fairly small and dim.

Globular cluster NGC 362

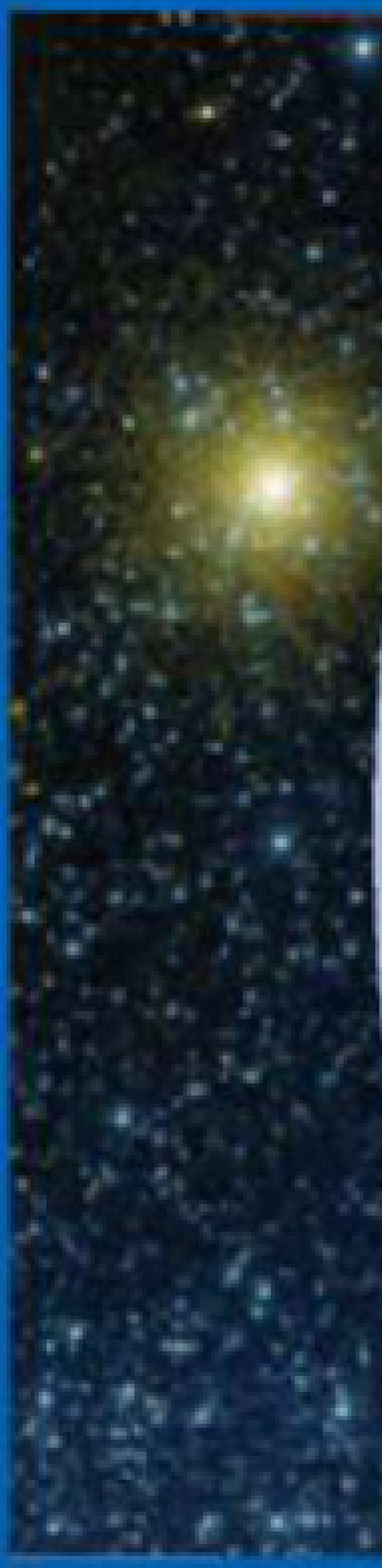
Viewable time: All through the hours of darkness

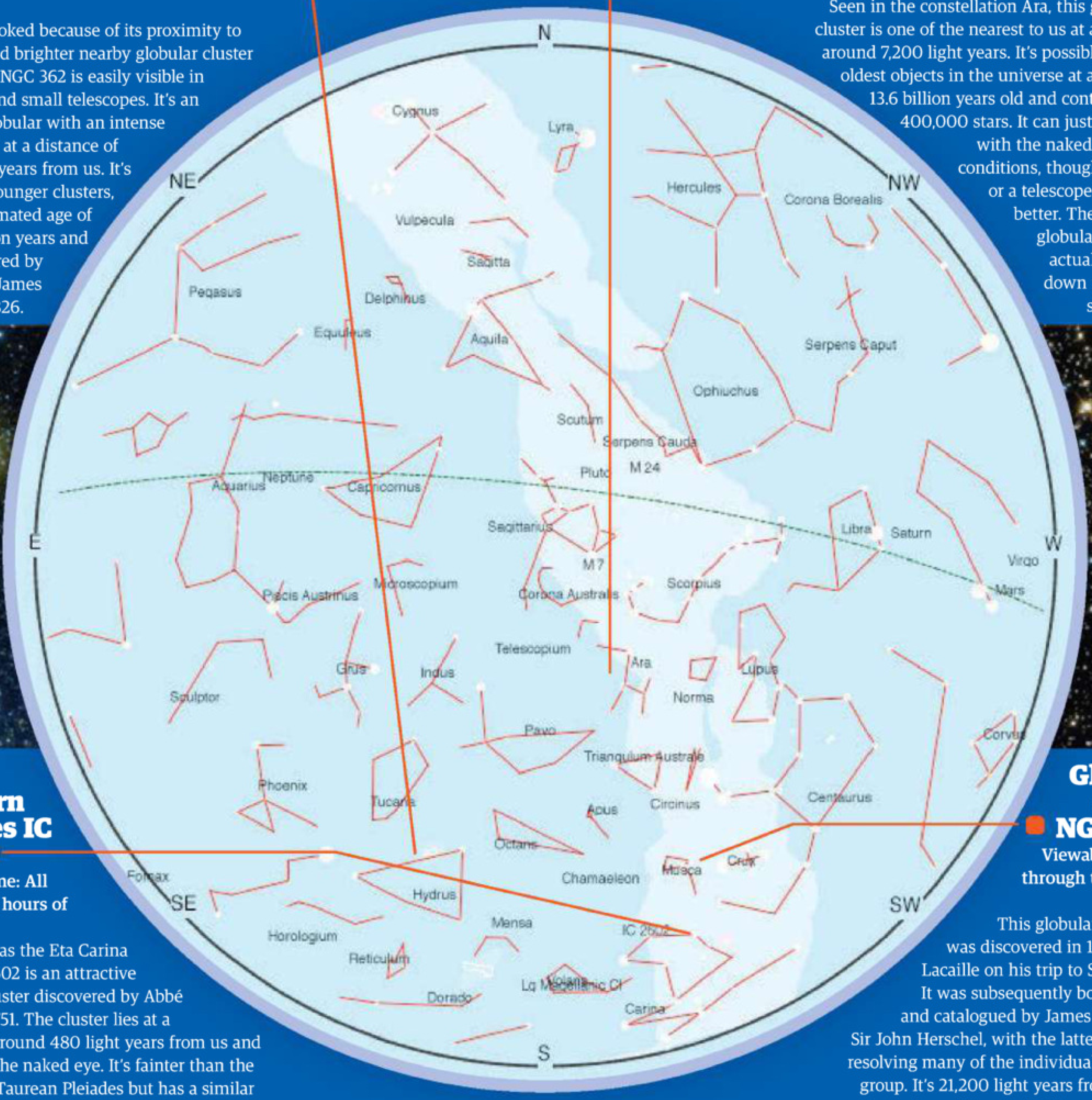
Often overlooked because of its proximity to the larger and brighter nearby globular cluster 47 Tucanae, NGC 362 is easily visible in binoculars and small telescopes. It's an attractive globular with an intense core and sits at a distance of 27,700 light years from us. It's one of the younger clusters, with an estimated age of only 12 billion years and was discovered by astronomer James Dunlop in 1826.

Globular cluster NGC 6397

Viewable time: All through the hours of darkness

Seen in the constellation Ara, this globular star cluster is one of the nearest to us at a distance of around 7,200 light years. It's possibly one of the oldest objects in the universe at an estimated 13.6 billion years old and contains around 400,000 stars. It can just be detected with the naked eye in good conditions, though binoculars or a telescope will show it better. The core of this globular cluster has actually collapsed down to a massive stellar group.





The southern Pleiades IC 2602

Viewable time: All through the hours of darkness

Also known as the Eta Carina cluster, IC 2602 is an attractive open star cluster discovered by Abbé Lacaille in 1751. The cluster lies at a distance of around 480 light years from us and is visible to the naked eye. It's fainter than the northern or Taurean Pleiades but has a similar form. Wide-field binoculars or a small telescope at low power are the best ways to view some or all of its 60 stars.

Southern Hemisphere

Globular cluster NGC 4833

Viewable time: All through the hours of darkness

This globular star cluster was discovered in 1752 by Abbé Lacaille on his trip to South Africa. It was subsequently both observed and catalogued by James Dunlop and Sir John Herschel, with the latter's telescope resolving many of the individual stars in the group. It's 21,200 light years from us in the constellation of Musca the Fly and is thought to be one of the older globular clusters, dating back around 12.5 billion years.

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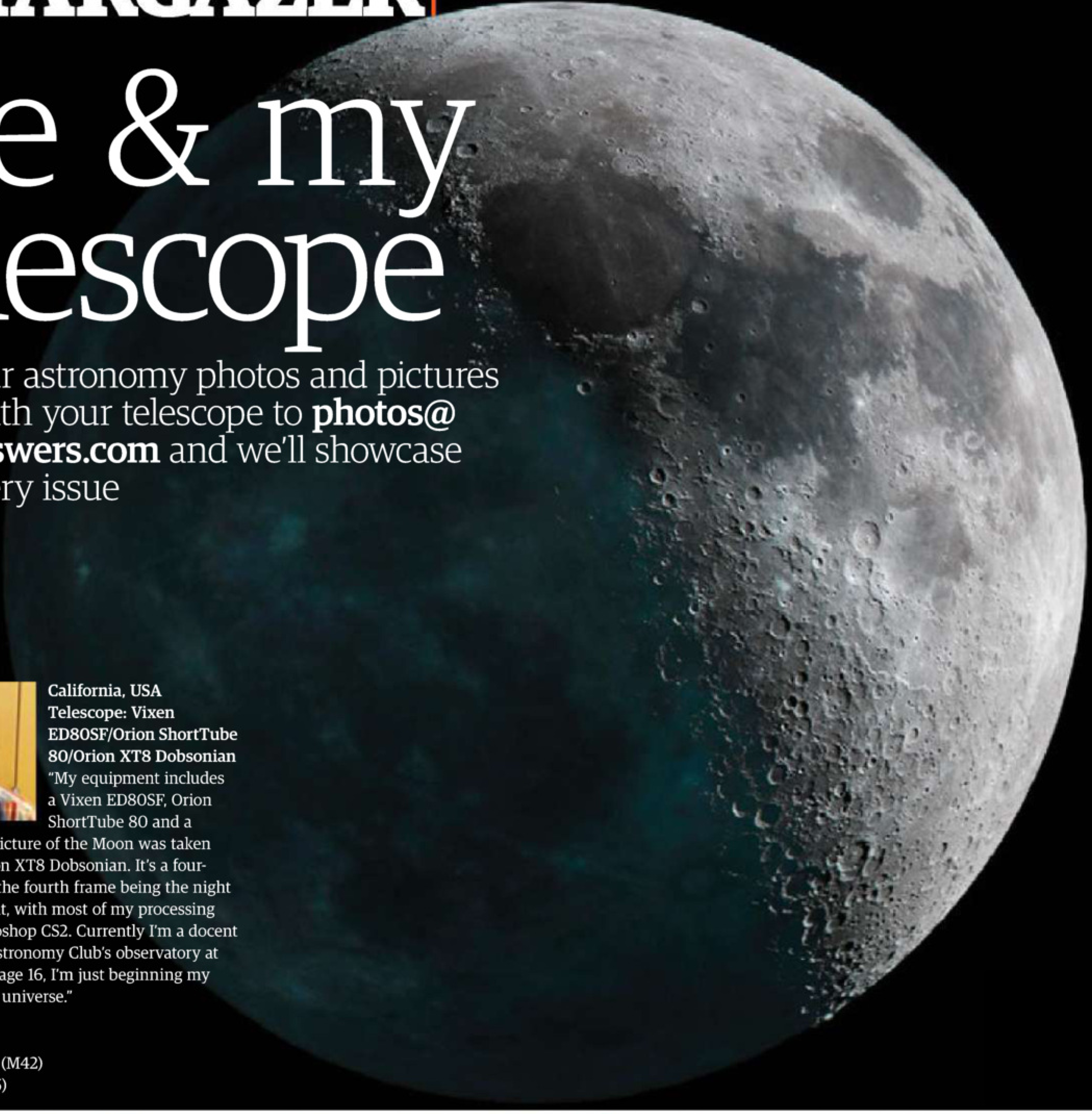
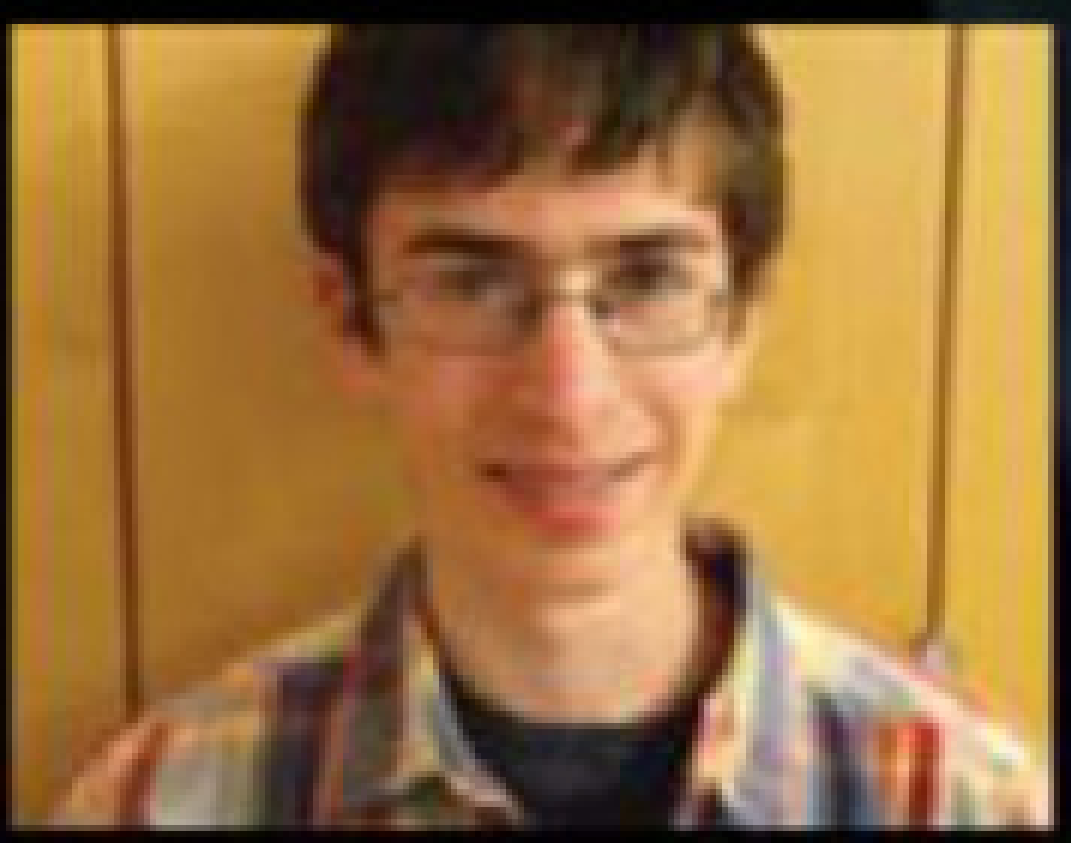
Me & my telescope

Send your astronomy photos and pictures of you with your telescope to **photos@ spaceanswers.com** and we'll showcase them every issue

01



Jacob Bers

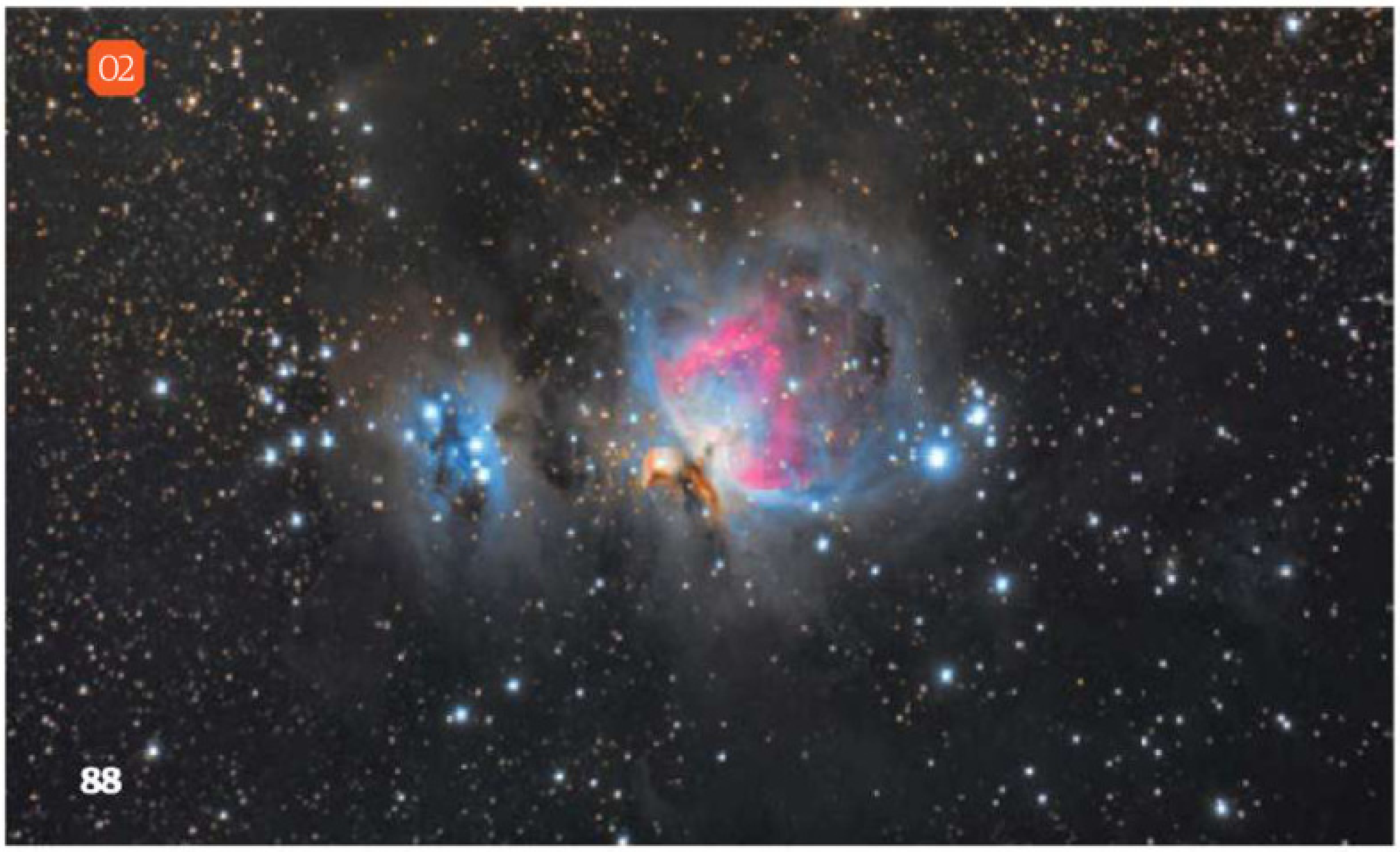


California, USA
Telescope: Vixen ED80SF/Orion ShortTube 80/Orion XT8 Dobsonian

"My equipment includes a Vixen ED80SF, Orion ShortTube 80 and a Nikon D5100. The picture of the Moon was taken with my trusty Orion XT8 Dobsonian. It's a four-frame mosaic with the fourth frame being the night side. I am self-taught, with most of my processing being done in Photoshop CS2. Currently I'm a docent for the Peninsula Astronomy Club's observatory at Foothill College. At age 16, I'm just beginning my adventures into the universe."

1. Earthshine
2. The Orion nebula (M42)
3. The Pleiades (M45)

02



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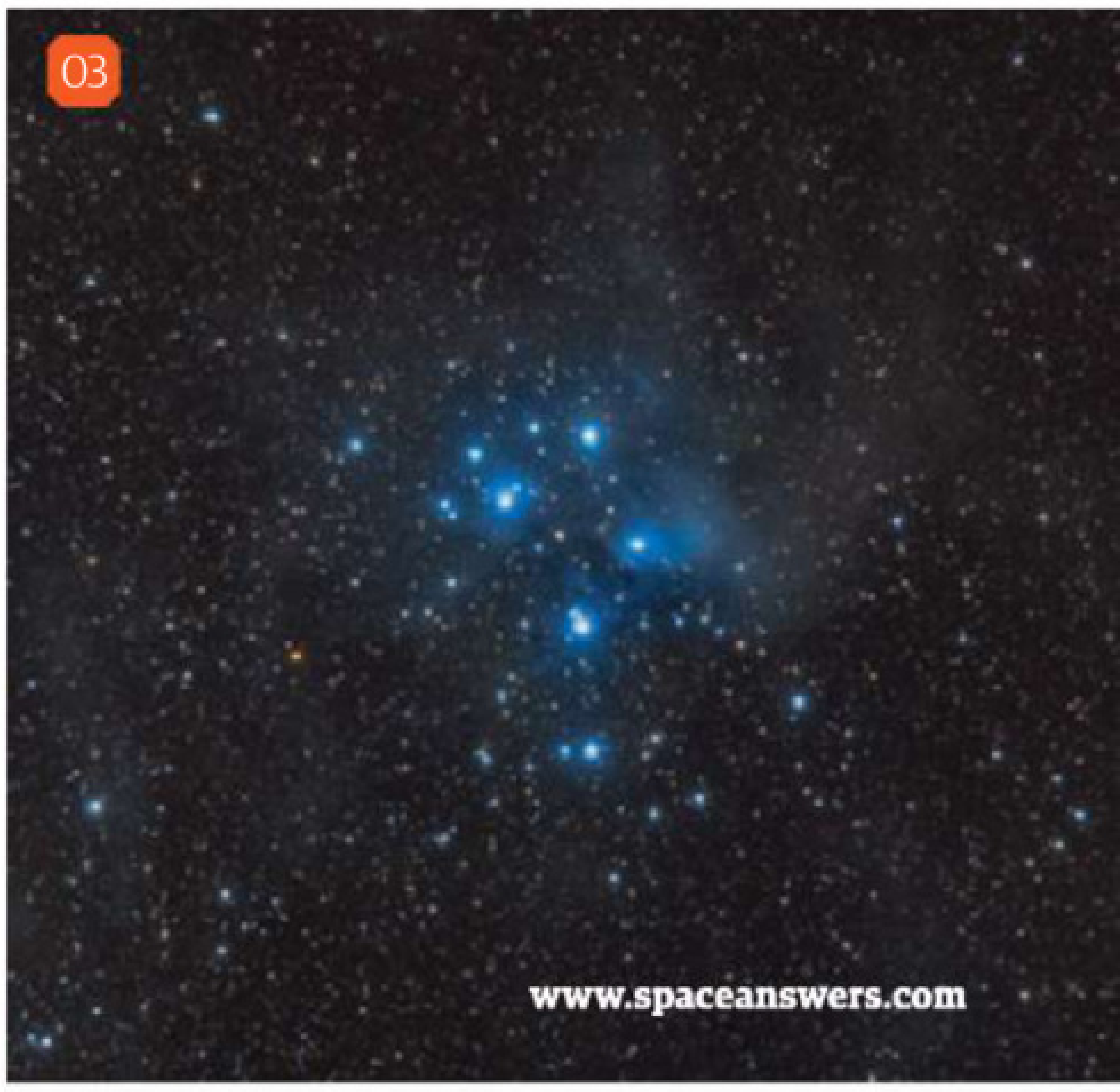
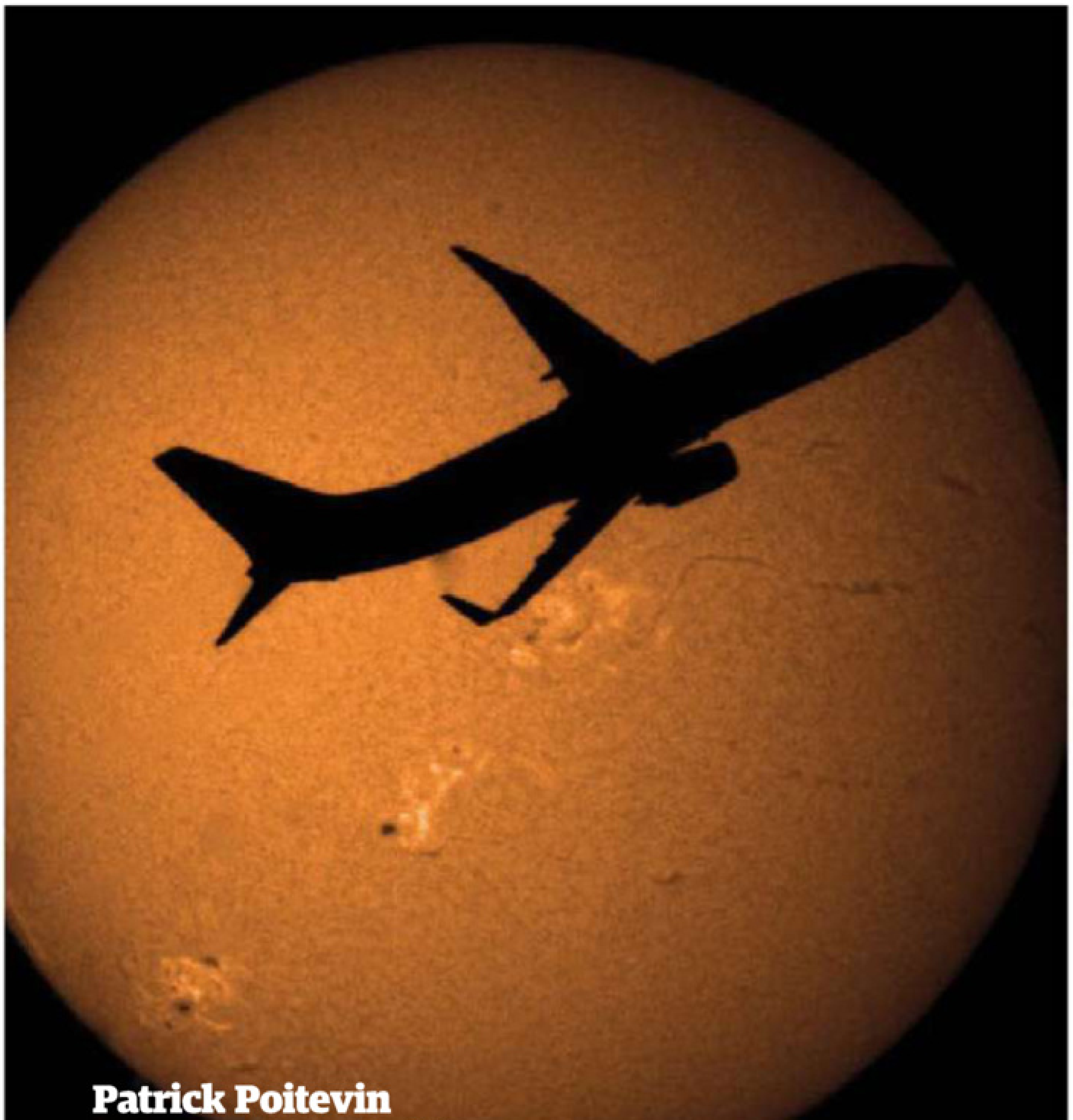




Patrick Poitevin

Derbyshire, UK

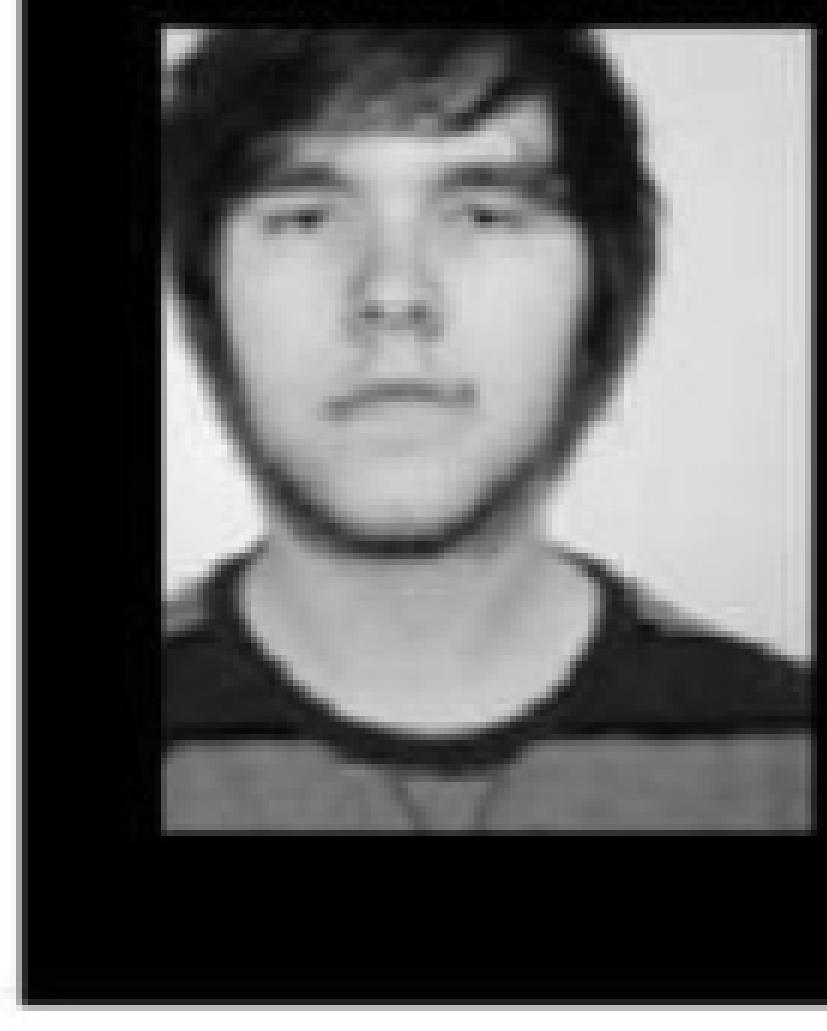
Telescope: Meade 200/Celestron C90

"I'm a keen solar observer. I have been travelling to view solar eclipses for many years and I have seen 42 so far. Besides our travels to see eclipses, my wife and I also travel to observe transits - we witnessed the transit of Venus and have seen five transits of Mercury. Earlier this month I was fortunate enough to see a plane passing in front of the Sun while imaging. Additionally, I was successful in capturing the International Space Station from home in Tissington, Derbyshire.

"I also organise international solar eclipse conferences where experts and amateurs from all over the world gather and share a passion for solar physics and eclipses."

Jupiter

Cameron Sorgi



California, USA

Telescope: n/a

"I'm a full-time VFX artist and astronomy enthusiast. I love studying all things to do with space and the universe. These photos were taken right from the balcony of my apartment in LA on a night when the sky was particularly clear."

Chris Sinclair

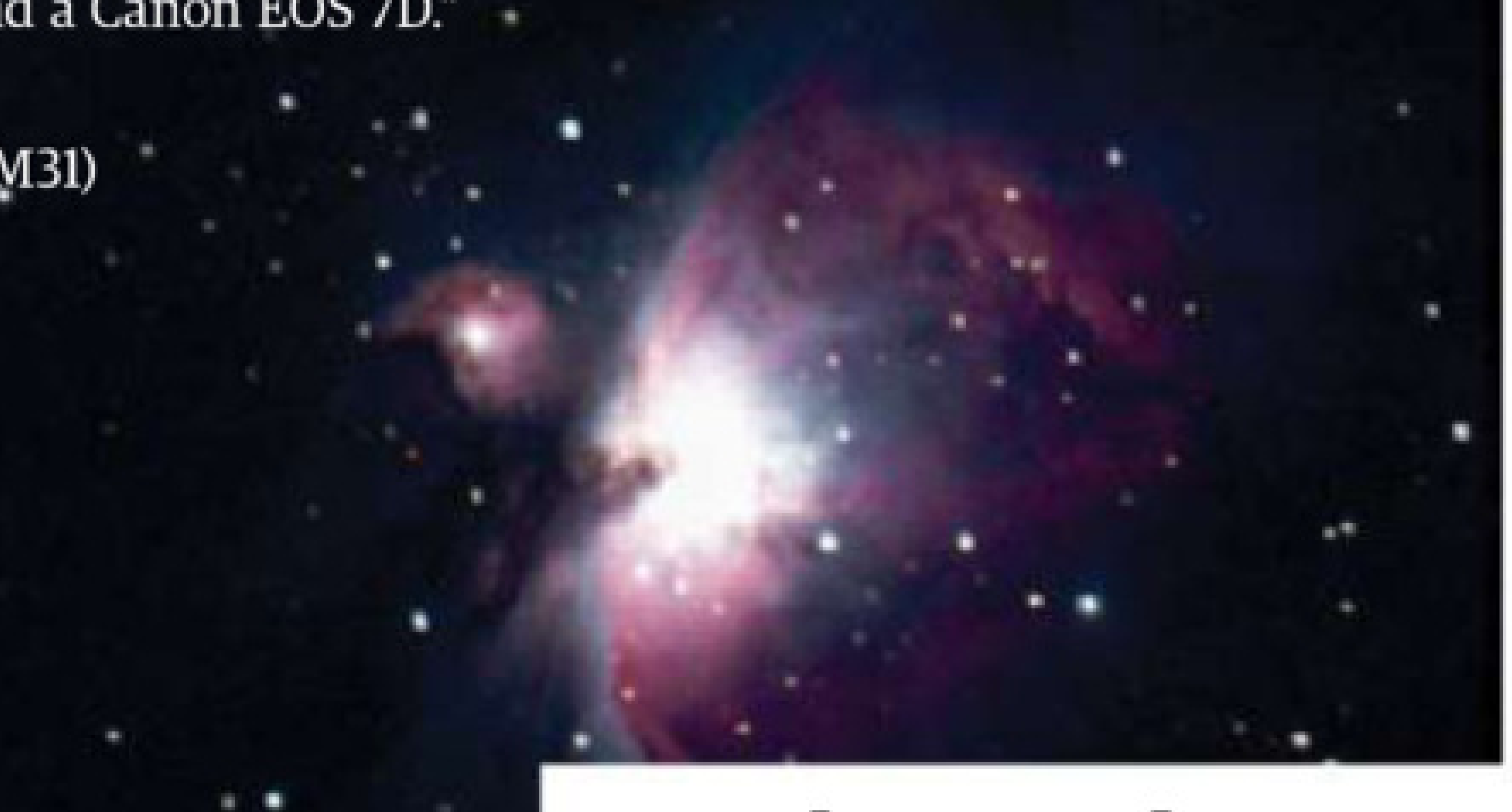
Caithness, Scotland

Telescope: Sky-Watcher ED80 Refractor

"I have been interested in astronomy all my life and got back into it with a telescope last year, where I quickly found myself delving into deep-space astrophotography. We have extremely dark skies and often nice aurora displays from our location at 58 degrees north. For all my images I used a Celestron CG5 GoTo Mount, with a Sky-Watcher ED80 Refractor, fitted with a x0.85 Focal Reducer and a Canon EOS 7D."

1. Orion nebula (M42)
2. Andromeda galaxy (M31)

01



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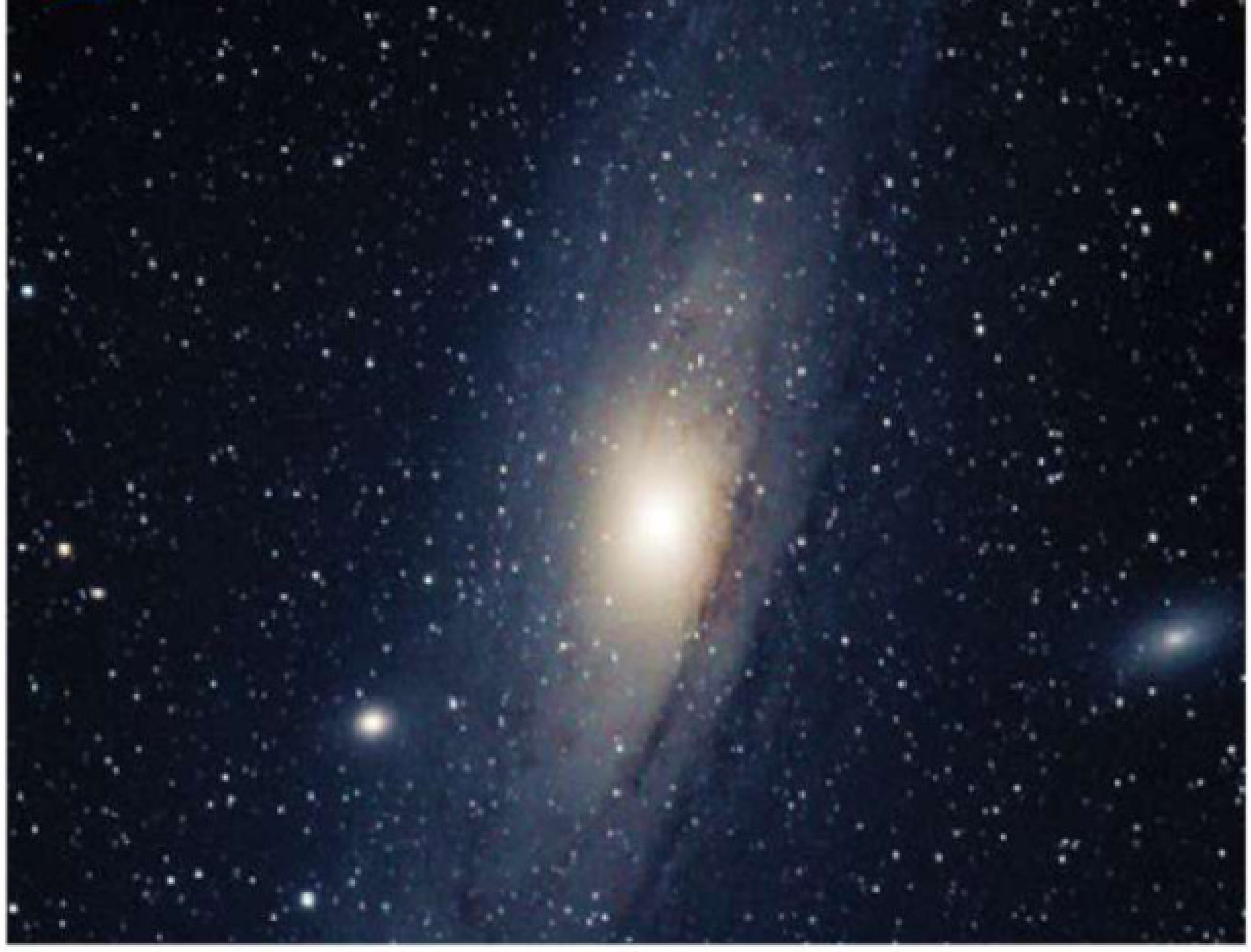


Send your photos to... @spaceanswers photos@spaceanswers.com

Stargazing stories

Email the story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**

Carolyn Kennett

Location: Cornwall, United Kingdom
Twitter: @CarolynKennett
Info: Astronomer for eight years
Current rig
telescopes: Meade LS 6", Sky-Watcher 90mm Mak, Coronado PST
Mount: Equatorial mount
Other: 10x50 binoculars

"It was a move to west Cornwall that reignited my childhood interest in astronomy. Arriving here ten years ago, I couldn't believe the number of stars visible in the night sky compared with the light-polluted city I had left behind. I spent many evenings after the move just sat in my garden trying to remember and relearn constellations that I had long forgotten.

"I started out by using just my naked eye, but soon was turning a pair of binoculars onto favourites such as the Orion nebula and the Andromeda galaxy. It wasn't until I purchased my first telescope, a Meade 6", that I became completely hooked.

"I mostly made observations within my own garden but soon learnt of some dark-sky locations and started to travel out farther to dark coastal locations... where the night is sometimes so clear that the Milky Way shines beautifully overhead.

"To learn more, three years ago I started a distance learning course in astronomy, which snowballed into doing a full degree in Astronomy. Although I love observing I've found that I equally enjoy the theoretical aspects to the subject and have been elected as a fellow of the Royal Astronomical Society.

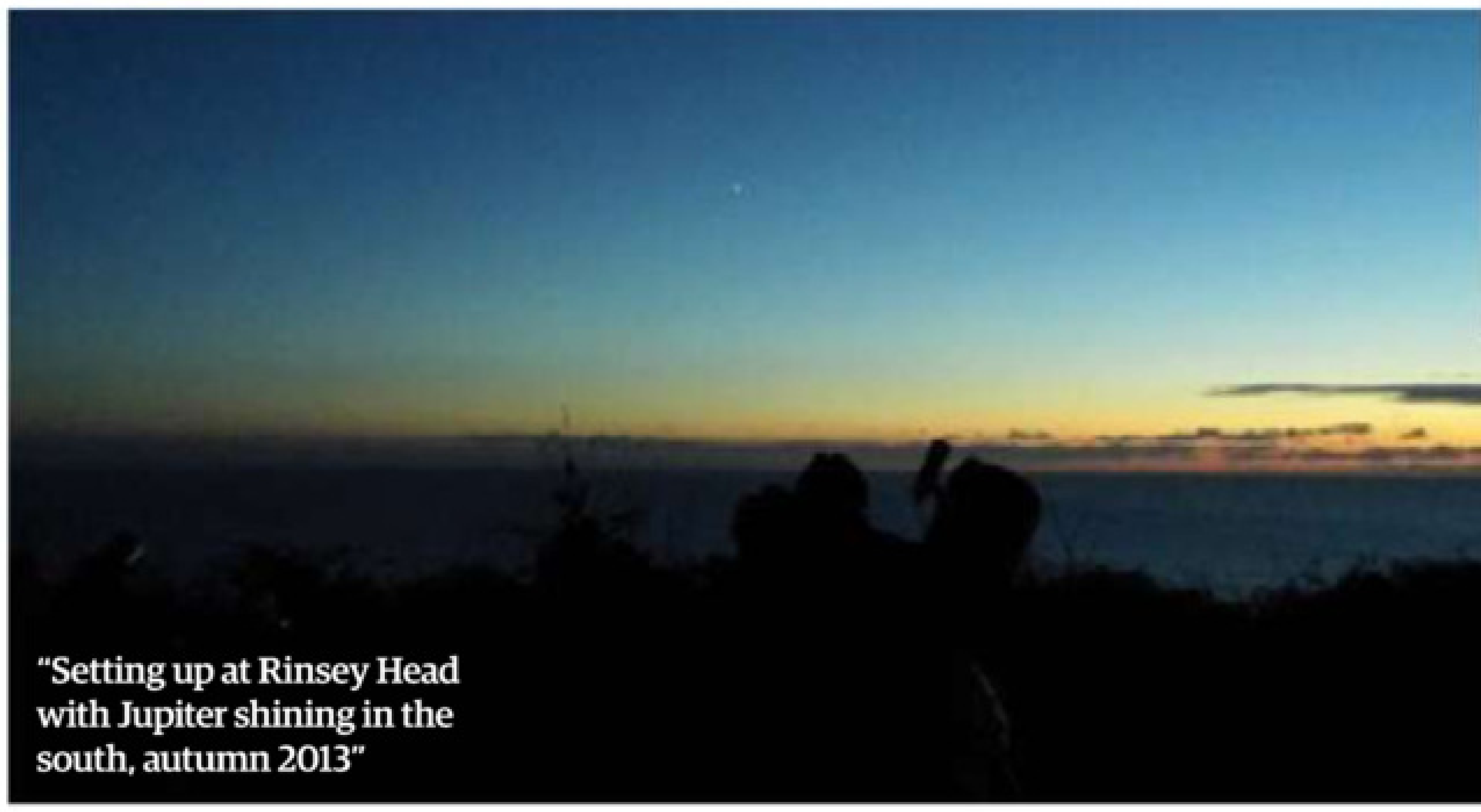
"It was about this time that I also became a member of a local astronomy group called Landsend Astronomers and discovered that I love the social aspect to astronomy. It's amazing the helpful hints and tips you can pick up along the way...

"I enjoy sharing my knowledge in the subject and have become a STEM ambassador with the intention of inspiring younger generations. When I look back, I've come a long way since I started sitting on my doorstep ten years ago, gazing up at what seemed to be random clusters of stars." ●

"Meeting Pete Lawrence and Paul Abel at a Perseid meteor event in Cornwall, August 2012"

"Showing fellow astronomers the view through my PST Coronado, summer 2012"

"Picture of the supermoon rising near Pendeen, June 2013"



"Setting up at Rinsey Head with Jupiter shining in the south, autumn 2013"

"Meeting Brian Cox at AstroFest 2013 in London"

Carolyn's top three tips

1. Connect with astronomers

I love the social aspect to astronomy and have met some helpful people. I hope that I have been able to give as much advice as I've received!

2. Keep a logbook

Looking back through your journey is something really special. Also you never know when your observations may be important to professional astronomers.

3. Use decent eyepieces

The telescope is only as good as your eyepiece. Using a poor-quality eyepiece will significantly limit your enjoyment of the hobby.

Send your stories and photos to... @spaceanswers @ photos@spaceanswers.com

Stephen MacGillivray

Location: Bath, United Kingdom
Info: Astronomer for three years (although had interest and telescope for longer)
Current rig
telescope: Celestron PowerSeeker 114
Mount: Sky-Watcher EQ5 Mount with synscan ver 3.35
Other: Canon EOS 500D, Nikon Binoculars 10-22 X 50, Revelation eyepiece set

"I am in the unenviable position of being both an astronomer and a Christian and I came to enjoy astronomy because of my faith. As such, my story is somewhat unique and my focus within astronomy will differ from many others. Although I no longer agree with their arguments, it was a book by creationists that motivated me to buy my first telescope approximately 15 years ago. I am, to a fair extent, on the fence with a lot of the debates, as I think humans have a lot more to discover before we can put all the pieces together.

"Similar to many people, I had difficulty getting used to the operation of my telescope and have only been using it actively for about four years. My current scope is the same as my original but I recently upgraded the mount. In astrophotography, a good mount is vital. My interest in astronomy has always been primarily visual. I am gradually learning the science behind it, but what draws me is seeing or capturing the beauty and breathtaking sights of the cosmos. These interests led me to try to take pictures through my telescope and after some attempts I managed to take a picture with my handheld camera through the eyepiece.

"The tone-mapped picture of the Moon and Venus was taken with a 70-200mm lens on a tripod. I have included this to show that if your interest is taking pictures of things beyond the Earth, then you don't need a telescope. However, it's important to have manual settings on your camera and the better the lens (interchangeable or otherwise), the better the image you will get.

"The last two pictures are my first attempts at deep-sky imaging. These can be achieved only with a tracking mount and DSLR or CCD camera. ■

Stephen's top three tips

1. Learn the sky

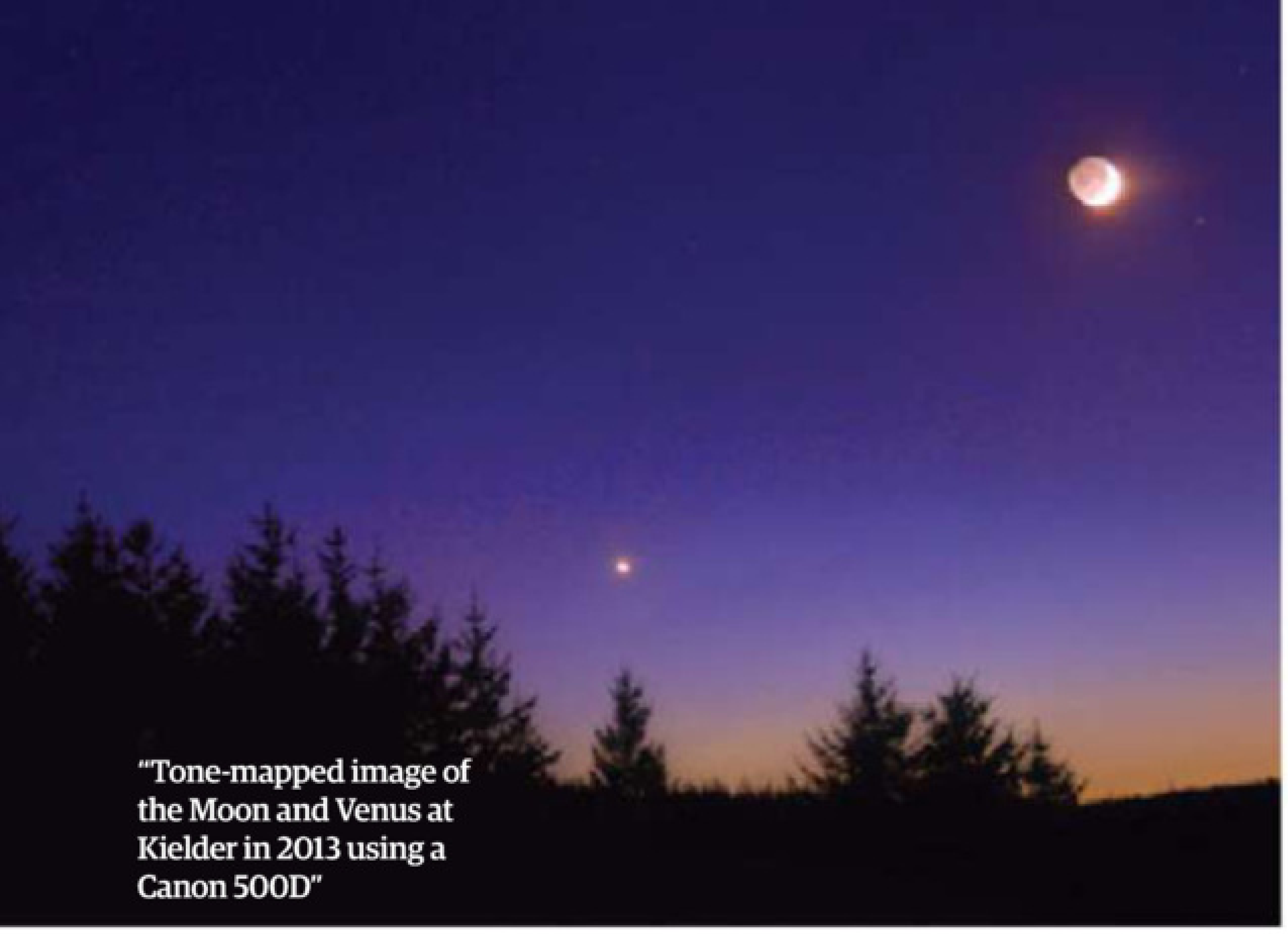
There are good apps for this on most tablets and phones. Mapping the night sky means that you can spend more time looking at an object, rather than finding it.

2. Develop a preferred method

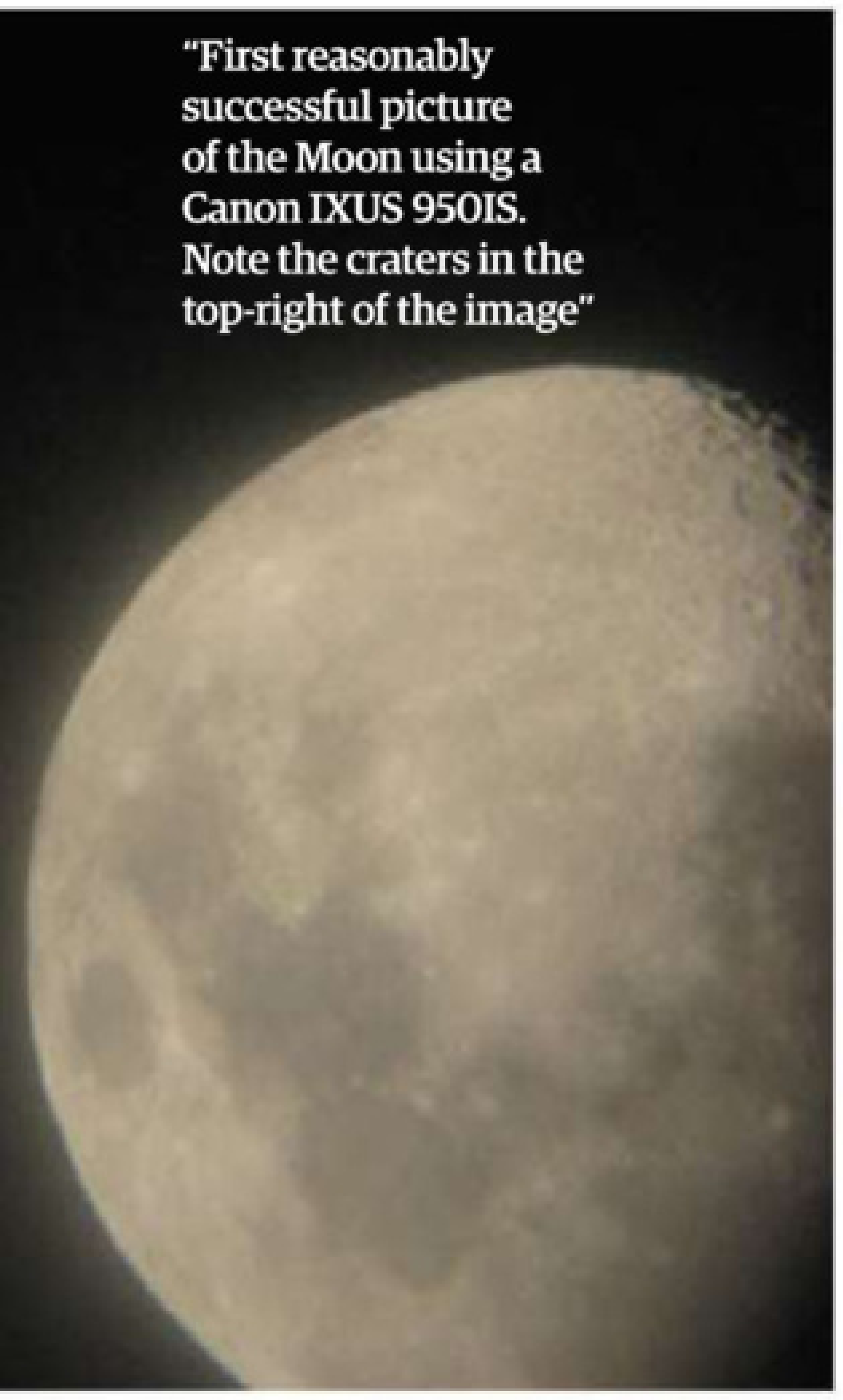
As soon as you know your field(s) of interest, decide whether you want to draw, compare or photograph objects and practise doing this.

3. Shoot manual

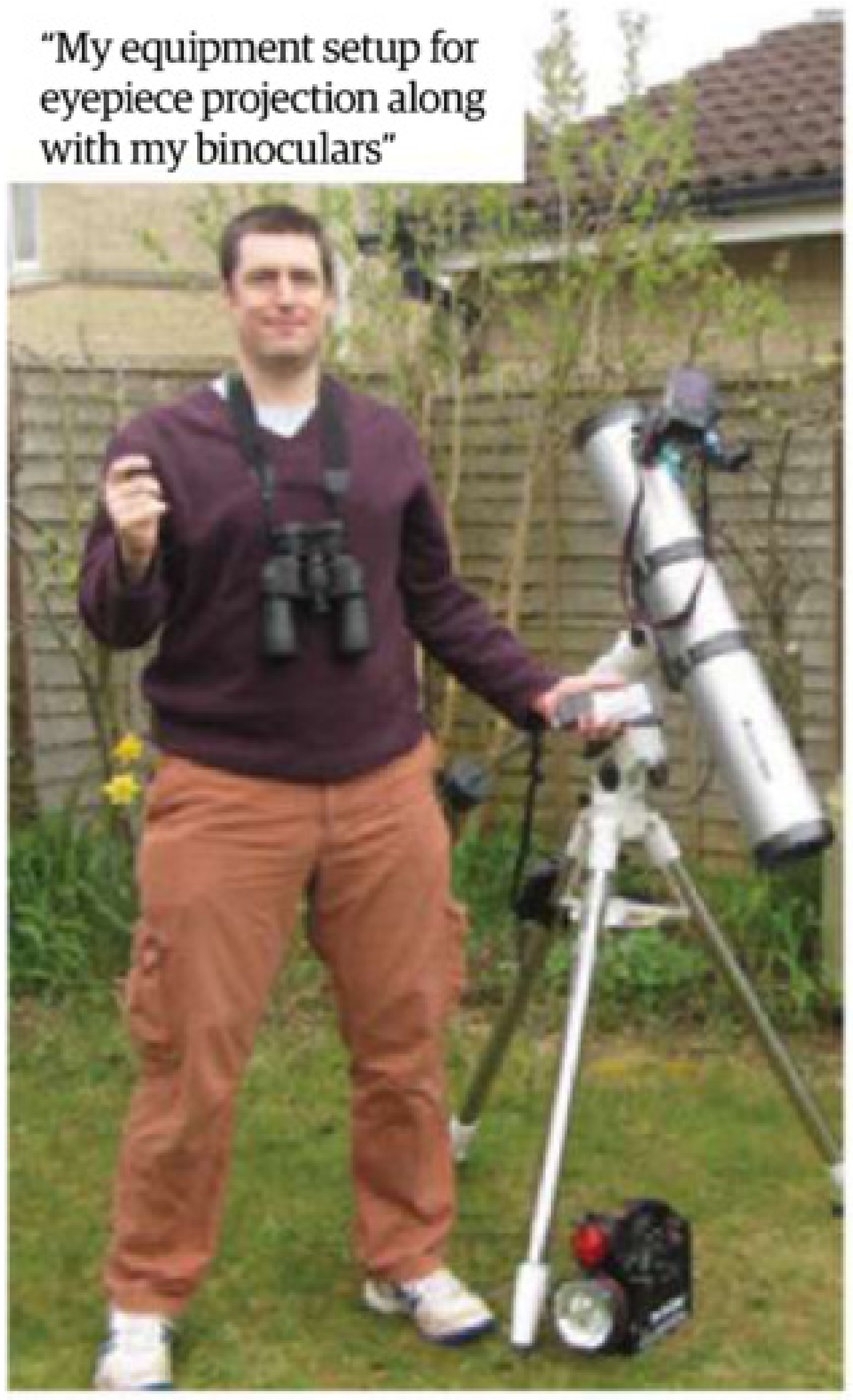
To image astro objects you need a camera with manual settings. For star trails, find some nice foreground, a tripod, the longest exposure and use ISO 800.



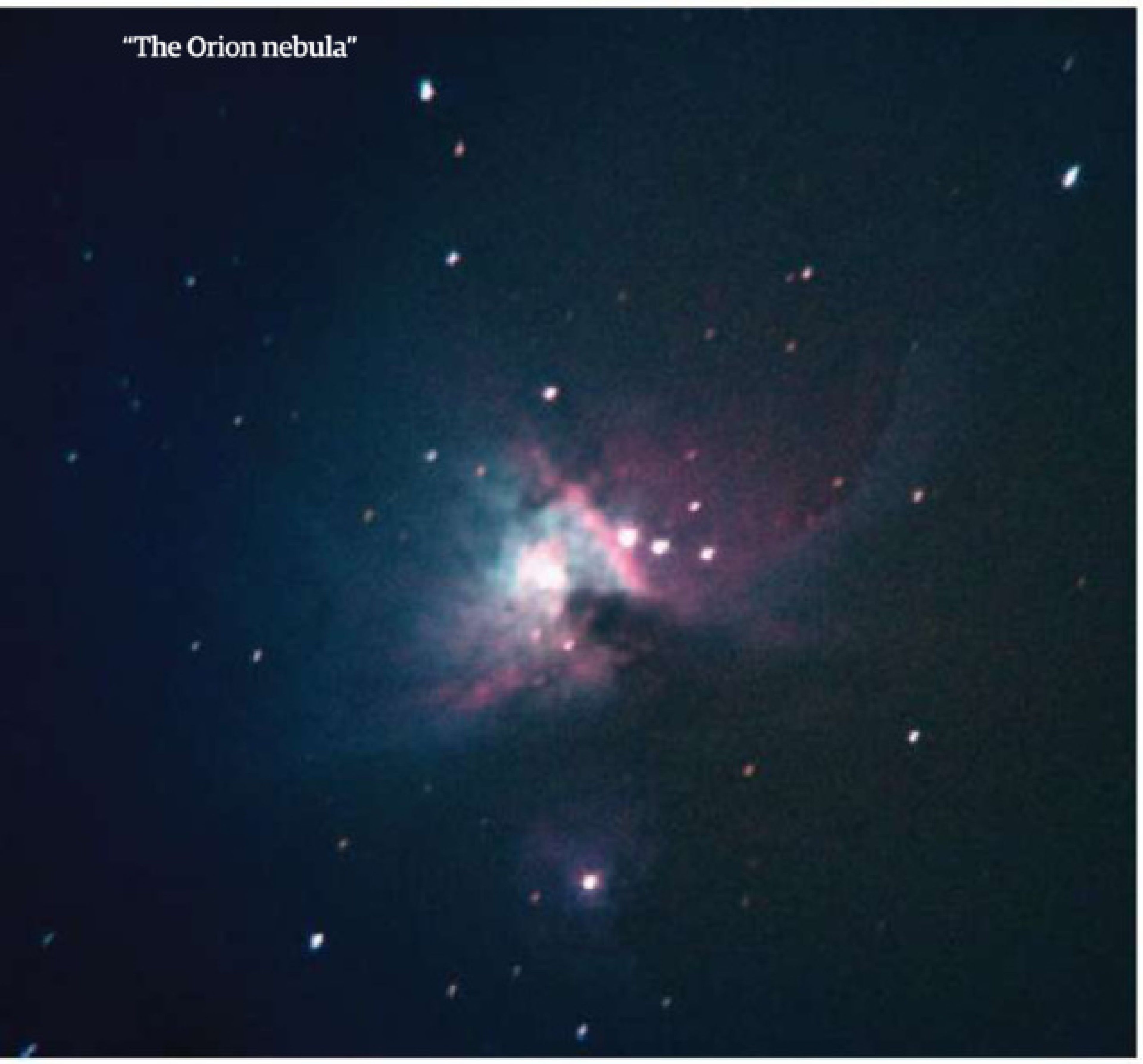
"Tone-mapped image of the Moon and Venus at Kielder in 2013 using a Canon 500D"



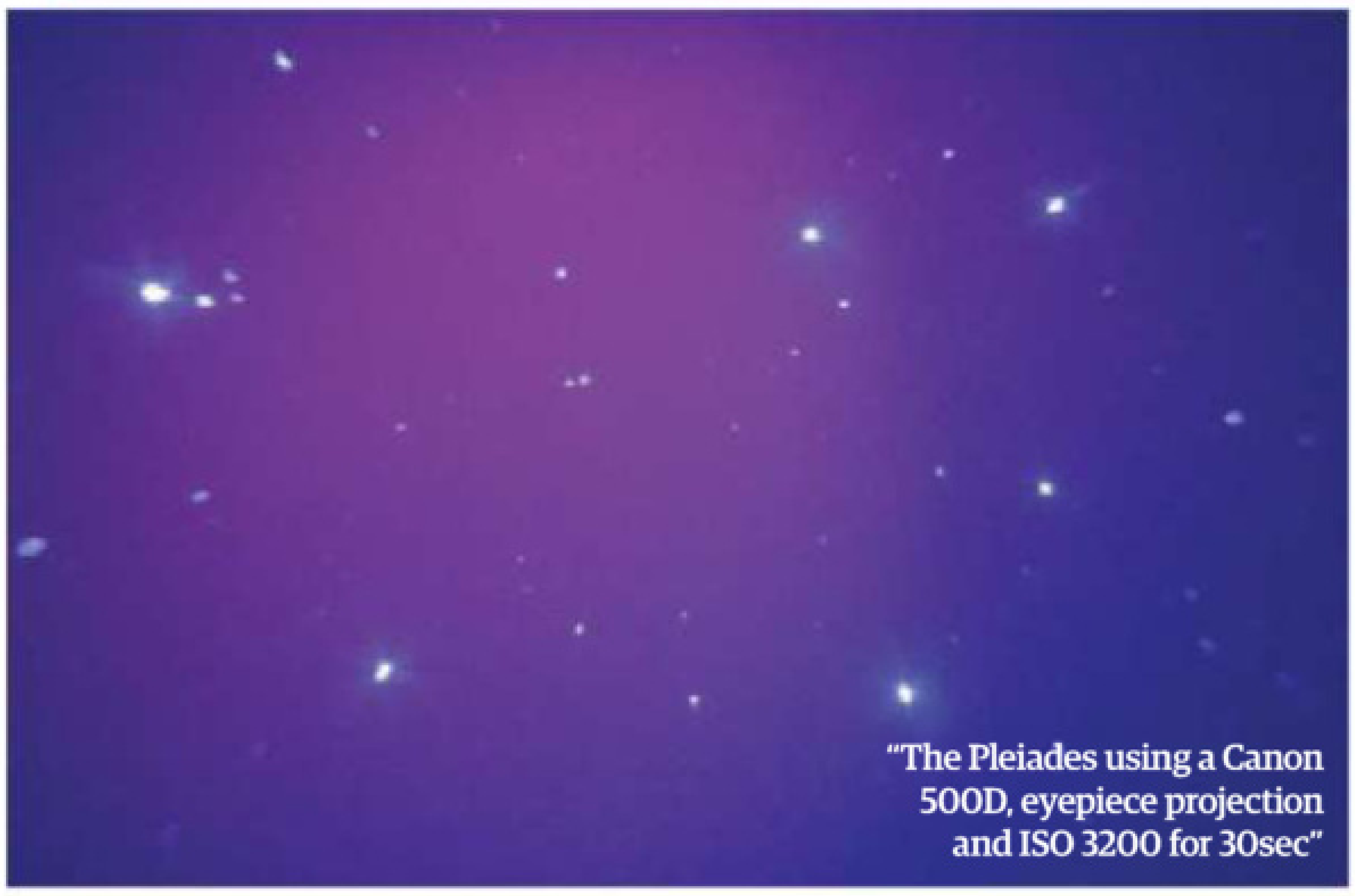
"First reasonably successful picture of the Moon using a Canon IXUS 950IS. Note the craters in the top-right of the image"



"My equipment setup for eyepiece projection along with my binoculars"



"The Orion nebula"



"The Pleiades using a Canon 500D, eyepiece projection and ISO 3200 for 30sec"

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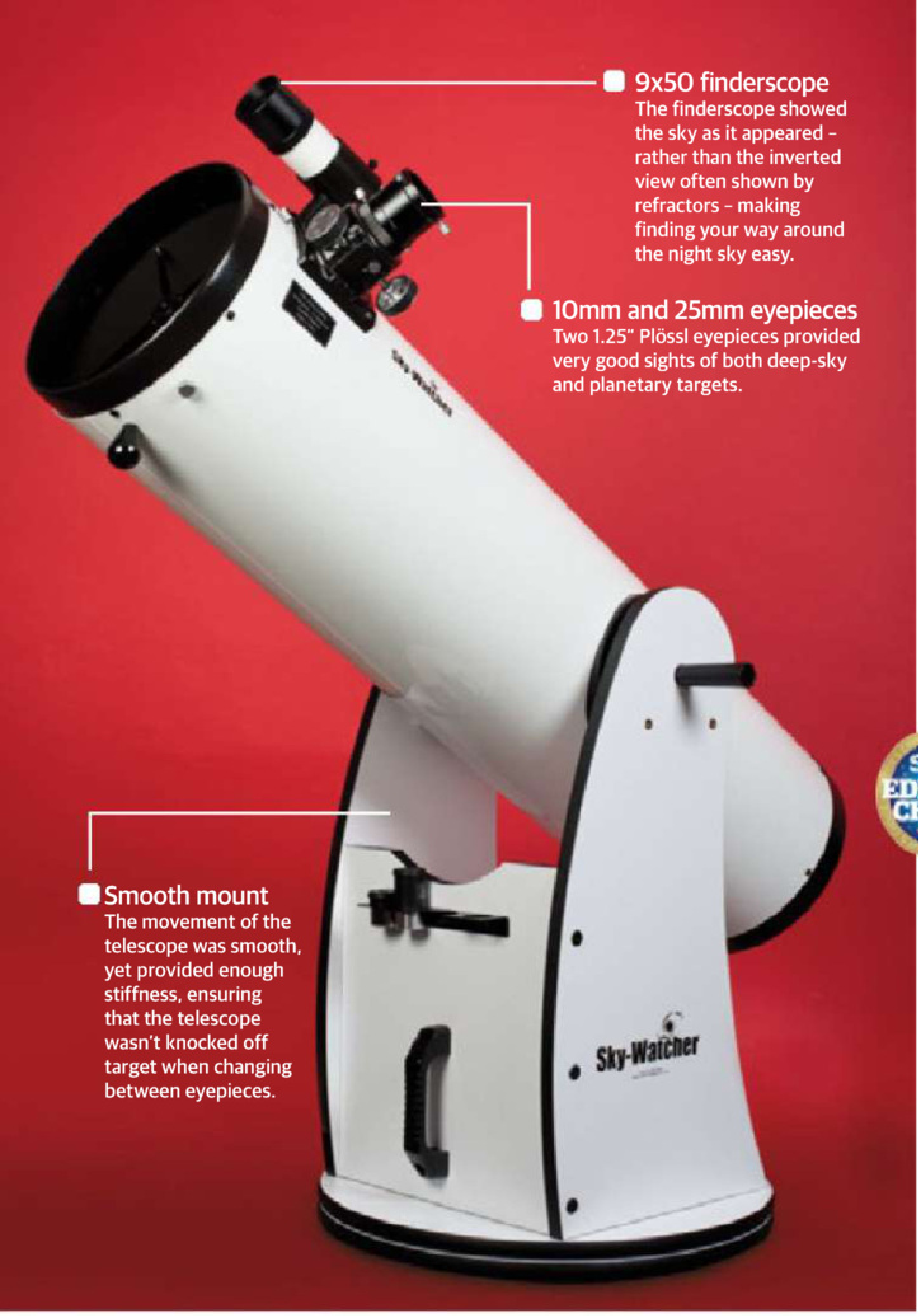
Sky-Watcher Skyliner-250PX

With light-gathering ability, this has everything you could need for night-sky observations



9x50 finderscope
The finderscope showed the sky as it appeared – rather than the inverted view often shown by refractors – making finding your way around the night sky easy.

10mm and 25mm eyepieces
Two 1.25" Plössl eyepieces provided very good sights of both deep-sky and planetary targets.

Smooth mount
The movement of the telescope was smooth, yet provided enough stiffness, ensuring that the telescope wasn't knocked off target when changing between eyepieces.

The wooden alt-azimuth mount is easy to set up and features a handy tray

With diffraction-limited optics, an aperture of 254mm (10in) and a highest practical power of 508x, this is an impressive upgrade

Telescope advice

Cost: £499 (approximately $840)
From: www.tringastro.co.uk
Type: Dobsonian
Aperture: 254mm (10in)
Focal length: 1,200mm (47in)

We love a Dobsonian and the Sky-Watcher Skyliner-250PX is no exception, certainly living up to the precedent in performance and ease-of-use these telescopes bring. Setting up the Skyliner-250PX is a breeze, especially with the comprehensive instructions to help you along if you get stuck in the process. However, we learned to our dismay that once you put this telescope together, you're unable to take it apart, so it's always a good idea to locate a storage space for your new instrument. The good news is that this model isn't too big and is very easy to move around with the assistance of lifting handles, although some may find that this could be a two-person job.

Supplied with two 1.25" eyepieces - a 10mm and 25mm Plössl - we found the optics of this Dobsonian to be incredible, providing very clear, sharp and pleasing views across an excellent percentage of its field of view.

Targeting star clusters, Jupiter as well as a range of nebulas, this instrument certainly didn't skimp on any detail. Additionally, diffraction spikes and light loss were minimal in comparison with other telescopes we've tested. Spherical aberration was kept at bay with high-quality paraboloidal primary mirrors. On the downside, the telescope's mount isn't driven, meaning only simple astrophotography can be attempted with it - but this didn't put us off.

This telescope gets a glowing report from us, while a selection of eyepieces and filters only serves to impress even more than the highly practical top power of 508x. ■

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Astronomy kit reviews

Must-have products for budding and experienced astronomers alike

1 Binoculars
Ostara Elinor 10 x 50

Cost: £199.99 / $N/A

From: www.opticalhardware.co.uk

The Ostara Elinor 10 x 50s are very light and the perfect answer to effortless observing for first-time or intermediate astronomers.

The fully multi-coated optics gave very good views and excellent contrast of a range of night-sky objects, however, we did notice a certain degree of flaring when observing brighter stars.

Over 70 per cent of the Elinor's field of view gave crisp sights with only a little over 20 per cent showing slight distortion. The Great Hercules globular cluster M13 appeared as a bright, fuzzy ball in the six-inch field of view. Double stars such as Alcor and Mizar were also easily split, revealing excellent contrast. The Orion nebula was a stunning sight, showing off its fuzzy-grey form and the brightest members of the Trapezium cluster.

The binoculars might be expensive, but certainly a worthwhile investment if you don't own a telescope.

2 Filters
Ostara Multiple Filter Wheel

Cost: £89.99 / $N/A

From: www.opticalhardware.co.uk

If you're looking for a quick way to use filters for your telescope while ensuring they're kept safe, then look no further than the Ostara wheel. These filters beautifully played up the many planetary features that the March sky had to offer.

The wheel unit itself is well made and not flimsy, promising a long life for many observing sessions. Pesky reflections are kept to a minimum, with the interior blackened. What's more, you don't need to remove the filters from the unit, but simply attach the nose of the wheel to your telescope while flicking through the filters you require.

If you prefer to upgrade your filters, the housing unit enables you to swap replacements in. For each filter that you wish to change, three screws need to be loosened – a small hindrance that in no way dampens the usefulness of this filter wheel.

3 Book
Space Hoax

Cost: £4.99 (e-book only) / $23.95

From: www.spacehoax.com

From the first page of *Space Hoax*, we begin where we left off in the book's prequel, *Moon Hoax*. We follow the life of CIA agent and former NASA candidate Peter Novak, who has landed safely back on Earth after thwarting the plans of the Chinese to gain space-race glory.

What soon becomes clear as we read on is that the Chinese are looking for revenge on America and we're soon catapulted on an adventure that takes a look at China's plan to sabotage the country's pride and joy – the International Space Station. It's up to Novak to save the stranded cosmonauts aboard the crippled station, but will he succeed?

We won't spoil the ending to this engaging novel, but what we can tell you is that Paul Gillebaard doesn't disappoint. Written with a close attention to detail and an excellent dose of action, you'll find it hard to put *Space Hoax* down.

4 App
NASA Visualization Explorer

Cost: Free

From: iTunes

With a treasure trove of information, this latest application is educational and interactive, providing you with tidbits of information. Even better, it's entirely free for all iPad and iPhone users, serving as the perfect companion to learn all about NASA, its missions, cutting-edge research and spacecraft. New stories are posted up every week, so it's important that you're hooked up to Wi-Fi or a suitable data connection on your iPhone.

We got stuck into the new updated version (1.9.1) of the NASA Visualization Explorer as soon as we downloaded it and found that there was no severe crashing of the movie player. The handy app also played audio seamlessly.

With there always being something new to learn, plus stunning illustrations and images along the way, the NASA Visualization Explorer gets a huge thumbs up!

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We've got the ultimate kit to enhance your experience under the night sky up for grabs

Courtesy of Optical Hardware (www.opticalhardware.co.uk) we've got an entire set of Ostara eyepieces and filters, complete with an aluminium hard case, for you to win this month.

With nine Plössl eyepieces (4mm, 5mm, 6.5mm, 10mm, 15mm, 2x20mm, 25mm and 40mm) you can push your telescope to the limit, grabbing great views of the planets and deep-sky objects that will leave you amazed from one observing session to the next. That's not all - three filters (Moon, polarising, green) will ensure that you get the best contrast and night-sky sights possible.

To be in with a chance of winning, all you have to do is answer this question:

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A: Neptune B: Saturn C: Mars

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Part of Brahe's nose was made of brass after he lost a chunk of it in a sword duel!

Tycho Brahe

The peculiar life of the last great naked-eye astronomer revealed

In an age of eccentric astronomers, Tycho Brahe was perhaps the most eccentric of them all. Rumoured to not only have a tamed elk in his residence but also a psychic dwarf, Brahe's life is one of both astronomical genius and bizarre tales. There aren't many other astronomers who can claim to have lost part of their nose in a duel over a mathematical formula, before going on to make some of the most significant astronomical observations and discoveries of their time.

Tycho Brahe was born on 14 December 1546 in Skåne, Denmark (now Sweden). The eldest son, his life would begin its unusual path when, at an early age, he was kidnapped from his parents Otte Brahe and Beate Bille by his uncle Jørgen Thygesen Brahe after they had supposedly promised a child to Jørgen and his wife but failed to fulfil the promise.

At the age of 12 Brahe studied law at the University of Copenhagen as per his uncle's wishes, but he quickly developed a love for astronomy. He soon realised becoming a great astronomer meant spending many nights poring over observational data and would often spend his evenings doing just that. His uncle requested he persevere with law, however, so when Brahe was sent on a study tour of Europe at the beginning of 1562 he was limited to performing astronomy in his spare time.

One of Brahe's defining characteristics was that part of his nose was prosthetic, revealed in 2012 to have been made out of brass. Brahe had received this disfiguring wound from another Danish nobleman, Manderup Parsberg, on 29 December 1566, after the two disagreed over a mathematical formula. Crossing swords was the only way to resolve their differences, apparently.

Prior to this, in 1565, Brahe's uncle had died of pneumonia and two years later Brahe fully devoted himself to astronomy. With the help of his maternal uncle, Steen Bille, he built an observatory and alchemical laboratory at Herrevad Abbey in former Denmark.

Brahe is often regarded as the last great naked-eye astronomer as it was not long after his time that Galileo invented the telescope. It was from his observatory that he began making notable discoveries including one on 11 November 1572: a very bright star in the constellation Cassiopeia, now known to be a supernova. His measurements revealed that it must have been very far away - farther than the Moon and the planets - challenging the commonly accepted theory that beyond the lunar orbit objects were in a state of antiquity.

Over the next two decades he made more and more significant discoveries from various observatories. He was the first to realise comets were farther away than the Moon, rather than within the atmosphere which had been previously believed. He also performed some of the most precise observations of the night sky at the time before the arrival of the telescope.

One of his biggest contributions to astronomy, however, actually came after his mysterious death in 1601. Brahe had been hugely protective of his work throughout his life but, with his passing, his assistant - famed astronomer Johannes Kepler - was able to use Brahe's detailed observations of Mars to formulate his groundbreaking laws of planetary motion.

Brahe's life was certainly an eventful one. Alongside personal drama he made some monumental discoveries and observations in the field of astronomy, and today he is still regarded as one of the most important astronomers of all time. Perhaps he would find it fitting then that one of the Moon's most notable craters in its southern Earth-facing region is named in his honour. ●

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Cover images
NASA, Adrian Mann, ESO

Photography
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Printing & Distribution
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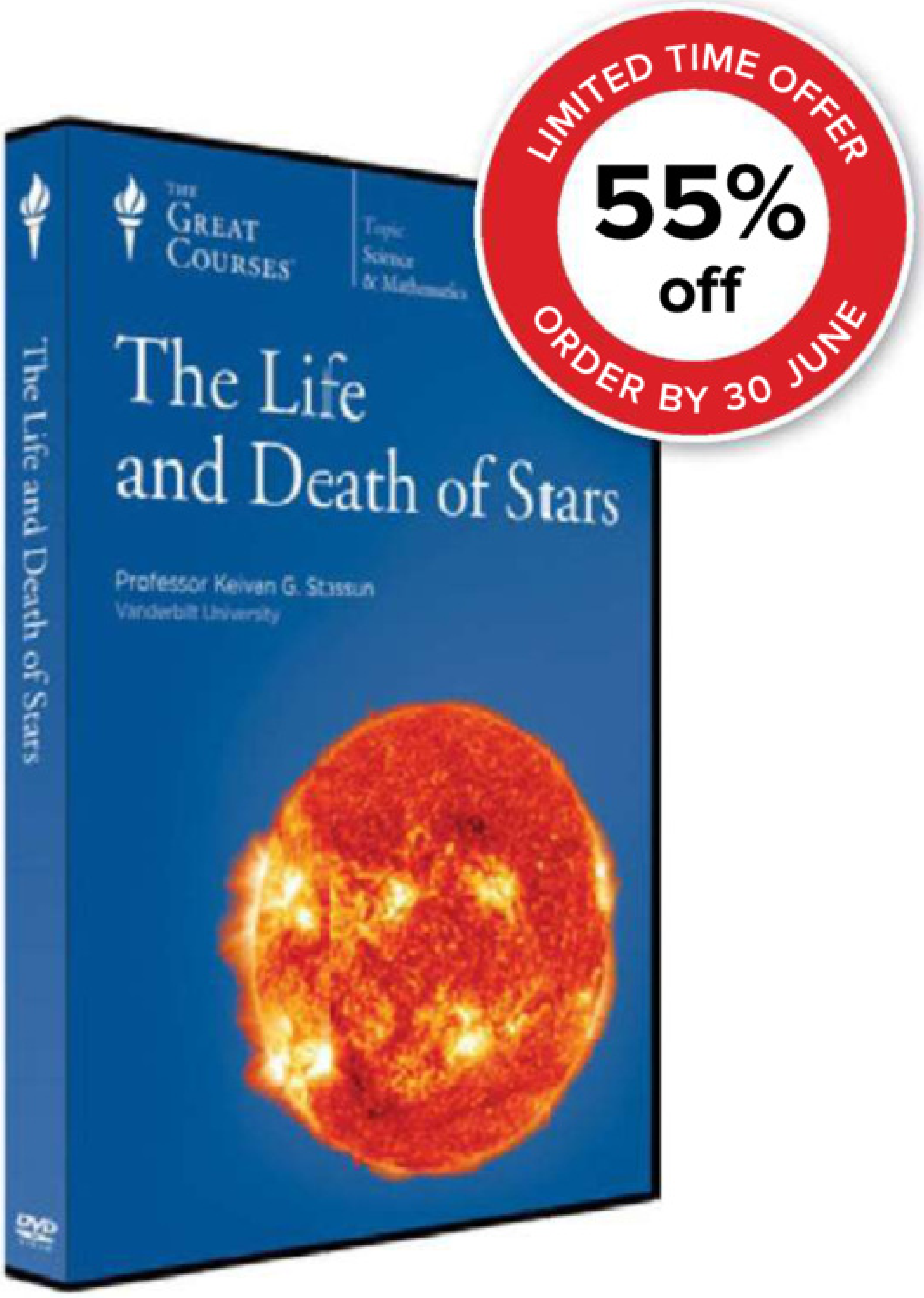

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